Technical Report on the Status of the Walkerton Water Supply System

November 2000

Ministry of the Environment

Technical Report on the Status of the Walkerton Water Supply System

Volume 1

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Appendix A - Documents Submitted to the Ministry
Appendix B - Ministry Field Orders

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EXECUTIVE SUMMARY

This report by the Ministry of the Environment (Ministry) examines actions that have been taken to restore and secure Walkerton's water supply, and bring it into compliance with the *Ontario Drinking Water Standards*.

It reports on actions taken by the Municipality of Brockton (Municipality) and the Walkerton Public Utilities Commission (PUC) including their response to Field Orders issued by the Ministry. These actions included steps taken to restore the potability of the water supply and steps taken to prevent a recurrence of contamination.

It outlines additional actions taken by the Ministry to audit and confirm restoration activities that were completed to comply with Ministry Orders.

The report provides an assessment of these actions, including the following overall conclusions:

- reports from the PUC, prepared by the Ontario Clean Water Agency and GAP EnviroMicrobial Services Inc., support the conclusion that restoration activities have eliminated the contamination from the water distribution system and from individual buildings and residences in Walkerton;

- analysis undertaken by the Ministry through its extensive audit and sampling programs confirms that the water distribution system and individual buildings and residences have been disinfected;

- Well 5 should be permanently plugged and abandoned. Further treatment is required at Well 6 as there is a potential for direct access of surface water into the well. The groundwater supply at this well may also be under the direct influence of surface water. While Well 7 exhibits the best raw water quality, there is some hydraulic connection with Well 6. Further treatment is therefore required;

- implementation of the filtration and chlorination treatment system for Wells 6 and 7 will provide an effective double treatment barrier to secure the water supply. Ministry sampling has confirmed the system's effectiveness in delivering water that meets the *Ontario Drinking Water Standards*;

- system upgrades and operating procedures that have been put in place will provide additional safeguards for the security of the water supply system, and;

- implementation of the requirements regarding Walkerton's water wells in this report will provide for the continuing security of the water supply system.

Based on all of the information provided to the Ministry, and the results of its audit and sampling programs, the Ministry of the Environment is satisfied that, with the exception of hardness (an operational guideline), the Walkerton water supply system is in compliance with the *Ontario Drinking Water Standards*.

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INTRODUCTION

This document is a technical report on the current status of the Walkerton water supply system. It is provided to the Medical Officer of Health for Bruce-Grey-Owen Sound, at his request, to assist in his decision regarding the lifting of the Boil Water Advisory issued on May 21, 2000.

The report is an assessment of the work done by the Municipality of Brockton (Municipality) and the Walkerton Public Utilities Commission (PUC) to restore and secure the water supply system. The Ministry of the Environment's (Ministry) assessment of the status of the Walkerton water supply system is based on:

- information provided by the Ontario Clean Water Agency (OCWA) on behalf of the PUC, on how the system has been restored and secured to comply with Ministry requirements;
- information provided by the Municipality on the hydrogeological work completed to comply with Ministry requirements; and
- the results of comprehensive audit and sampling programs completed by the Ministry, including the testing of over 5,000 water samples.

Appendix A provides a complete list of the documents submitted to the Ministry which were considered in the development of this report.

The report begins with a brief description of Ministry actions since May 22, 2000.

Part two of the report speaks to the restoration of the water supply system. It outlines the remedial steps taken by OCWA to disinfect the water distribution system and all buildings in Walkerton. The results of the Ministry's audit and sampling programs to confirm the effectiveness of the disinfection are discussed.

Part three of the report speaks to the security of the system. It discusses the hydrogeological work that has been completed in relation to Walkerton's wells and the actions necessary to further upgrade, repair and secure these wells. It also discusses other measures that have been taken to provide for the security of the system, including the filtration system at Wells 6 and 7 and the Ministry's sampling to confirm its effectiveness.

The report ends with the Ministry's conclusions.

PART ONE: MINISTRY ACTIONS

The *Ontario Water Resources Act* (OWRA), which is administered by the Ministry, sets out requirements for the approval of new water supply systems or changes to an existing water supply system. It sets out a basis for sampling and reporting requirements and provides for the establishment of requirements for the operation of water supply systems. It also deals with the protection of public water supplies, gives the Ministry the authority to regulate water supply systems and sets out requirements for permits to take water.

The Ministry's role in administering the OWRA includes establishing drinking water quality and operating standards, known as the Ontario Drinking Water Standards (ODWS).[1] The ODWS, which have the force of law, replaced the *Ontario Drinking Water Objectives* in August 2000.

The ODWS regulate the manner in which owners and operators of municipal water treatment and distribution systems fulfil their responsibility to supply safe drinking water to the public. The Ministry also issues approvals, undertakes education initiatives and compliance/enforcement activities in relation to the responsibility that owners and operators have to produce and distribute safe drinking water.

In the event of non-compliance with the ODWS, or a Certificate of Approval, the Ministry can order corrective action. However, it is the Medical Officer of Health, not the Ministry, that determines whether or not the drinking water is safe and whether or not a Boil Water Advisory should be issued or lifted.

On May 22, 2000, the Medical Officer of Health for Bruce-Grey-Owen Sound asked the Ministry to investigate the operations and security of the Walkerton water system.[2] On May 25, 2000, the Ministry issued the first in a series of orders on the restoration of the Walkerton water supply system.

As a first step, the Municipality was required to retain the services of a qualified operating authority to oversee the operation and maintenance of the water system. On May 25, 2000 the Ontario Clean Water Agency (OCWA) assumed control of the operation of the system. The May 25, 2000 Ministry Order also set out a series of requirements to begin flushing the distribution system and to secure Walkerton's water supply against possible sources of contamination.

Representatives from OCWA and its agents, the Municipality's engineering and hydrogeological consultants and Ministry technical staff met to discuss restoration requirements. The Municipality and OCWA then submitted a plan to the Ministry and, following Ministry comments and the inclusion of any needed revisions, the Ministry issued an order for the required work, including a schedule for completion and a requirement for a report on compliance. This process was followed for the development of most of the work requirements incorporated into subsequent Ministry orders.

Over the course of the summer, the Ministry required the Municipality and the PUC to take a series of actions, including system upgrades and the decontamination of the Walkerton distribution system and all plumbing connected to it, to bring the system into compliance with the requirements of the ODWS. Please see Appendix B for a summary of the Ministry's Walkerton Field Orders.

In order to provide an additional level of verification for the work completed by the Municipality and the PUC in response to Ministry Orders and in order to verify that Walkerton's water supply had been brought into compliance with the ODWS, the Ministry developed and implemented a series of extensive audit and sampling programs.

The Ministry undertook another important role in responding to the *E. coli* outbreak. From early June, 2000 it provided alternate water supplies to the South Bruce Grey Health Centre (Walkerton Hospital), the Brucelea Haven Home for the Aged, the Maple Court Villa Retirement Home and the Walkerton Jail. A detailed discussion of the alternate water supply program, including the results of its sampling program, is provided in Appendix C.

The Ministry also facilitated a number of additional precautionary measures, including:

- Working with the Municipality on the incineration of its stored sewage biosolids so that none of this material was land applied. The biosolids were tested and no *E. coli* O157:H7 was detected. The stored biosolids were shipped to an approved facility and subsequently incinerated. This same approach will also be taken for the next six months of stored biosolids.

- The pumping of septic tanks (51) within Walkerton's former town boundaries so that none of the material was applied to the land. The septage was processed at Walkerton's sewage treatment plant. The tanks were pumped in September because most of the people who had become ill would no longer be shedding bacteria.

- Working with the Municipality to extend the period of sewage effluent disinfection at the municipal sewage treatment plant.

PART TWO: RESTORATION OF THE WATER DISTRIBUTION SYSTEM

The actions undertaken to restore Walkerton's water distribution system are described in detail in *The Ontario Clean Water Agency's Report to the Walkerton Public Utilities Commission on the Operational Measures Taken to Address the E. Coli Water Contamination in the Town of Walkerton* (OCWA Report). The OCWA Report, dated October 17, 2000, was submitted to the Ministry on October 20, 2000.

OCWA undertook the following activities on behalf of the PUC to disinfect and restore the water distribution system, including the plumbing in all buildings and residences in Walkerton:

- watermain flushing and standpipe cleaning;
- elimination of watermain dead ends;
- watermain swabbing;
- building-by-building disinfection and flushing; and
- watermain replacement.

Each of these activities, including OCWA's sampling activities, are outlined briefly in this part of the report.

The Ministry's assessment of the effectiveness of OCWA's restoration activities follows. The assessment is supported by a series of extensive audit and sampling programs implemented by the Ministry to confirm that the restoration work was effective in disinfecting Walkerton's water supply system.

The Ministry's audit and sampling programs are also discussed in this part of the report.

OCWA's Restoration Program

Watermain Flushing and Standpipe Cleaning

On May 25, 2000, OCWA assumed the management of system operations on behalf of the PUC. On the same day, the Ministry ordered the thorough and complete flushing of the water distribution system and the cleaning of Walkerton's two water standpipes (water storage facilities).

Watermain flushing refers to the practice of opening fire hydrants to cause a large volume of chlorinated water to pass through an isolated section of the watermain to remove settled and suspended material and contaminants. (Reference should be made to Section 6.0 of the OCWA Report for a description of this activity.)

The system flushing and standpipe cleaning program also included a daily water sampling program at 21 strategic locations throughout Walkerton beginning on May 29, 2000.

OCWA has reported that:

- Walkerton's distribution system was flushed completely, that some portions were flushed more than once and that bacteria and loose sediment were effectively removed from the distribution system;
- Walkerton's two standpipes were cleaned completely and disinfected using water containing a minimum of 2 mg/L of chlorine to fill the standpipes, addressing any concerns of bacteria in the standpipes; and
- there were no incidents of adverse samples reported from the distribution system from the period May 29, 2000 to June 12, 2000, immediately following the completion of the flushing program.

OCWA concluded that the flushing operation was successful in removing suspended contaminants from the water distribution system.

Elimination of Watermain Dead Ends

Dead end watermains refer to sections of watermain that are capped and do not loop back to connect with any other section of the watermain. With a dead end there is no continuous flow of water through that section of watermain.

Without a continuous flow of water, dead ends can present an opportunity for the accumulation of sediments, biofilm and/or iron oxides. As this build-up can harbour bacteria, it is common practice to flush the dead ends through outlets known as "blowoffs". Fire hydrants can also be used for this purpose.

In Walkerton, there were many dead ends which did not include blowoffs or hydrants.

OCWA responded by installing hydrants and blowoff valves to allow the increased movement of water through the dead ends, increasing the effectiveness of flushing operations. (Reference should be made to Section 7.0 of the OCWA Report for a full description of this work.)

In its report, OCWA stated that:

- a total of 35 dead end locations were investigated between May 29, 2000 and July 31, 2000;
- fire hydrants were installed at 10 of these locations, two inch blowoff lines were installed at 14 other locations; and
- eleven of the dead ends investigated were found to terminate within buildings and could therefore be flushed effectively through the building-by-building disinfection process.

OCWA concluded that this work allowed for the flushing of the 35 dead end locations that might have contained outbreak organisms if left unchecked.

Swabbing of the Water Distribution System

Swabbing refers to cleaning the interior surfaces of watermains by forcing a foam swab through the pipes, effectively scouring any material build-up that could potentially protect bacteria such

as *E. coli* O157:H7 from chlorine. (Reference should be made to Section 8.0 of the OCWA Report for a description of this activity.)

Watermain swabbing is usually done on pipes with diameters of 100 mm (4") and greater. Pipes of a smaller diameter are scoured using the high velocity water flow that can be achieved with a smaller diameter pipe.

While system flushing is extremely effective in removing suspended bacteria from smaller distribution piping, it is not necessarily completely effective in dislodging all material build-up from within larger pipes. The Ministry, therefore, required that the watermains be swabbed.

In Walkerton, 100 mm cast iron pipe was found to contain a build-up of inorganic material (e.g., iron oxide and hard water scale) which reduced the pipe diameter to a point where swabbing was not practical. As a result, the swabbing of watermains in Walkerton was limited to watermains of 150 mm diameter and larger. The 100 mm cast iron watermains were replaced, as discussed later in this section.

The swabbing program began on June 11, 2000 and was completed on July 10, 2000. In its report, OCWA stated that:

- of Walkerton's 41 kilometres of watermains, 31 kilometres of 150 mm to 400 mm pipe were swabbed a minimum of four times using highly chlorinated water (300 mg/L) to force the swabs through the watermains;
- swabbing effectively removed and reduced the accumulated biofilm from within the large diameter pipes (OCWA cites as evidence the increase in the system chlorine residual and the low number of adverse samples reported immediately following the completion of the swabbing of the watermains); and
- the preliminary results of a biofilm experiment undertaken by GAP EnviroMicrobial Services Inc. (GAP), OCWA's microbiological consultants, showed that the OCWA's swabbing and disinfection program carried out was successful in destroying any established population of *E. Coli*, *E. Coli* O157:H7 *and Campylobacter jejuni* inoculated into the biofilm.

Building-by-Building Disinfection and Flushing Program

On June 13, 2000, the Ministry ordered the Municipality and the PUC to decontaminate the water distribution system and all plumbing connected to it.

A Building-by-Building Disinfection Program for Walkerton began on June 14, 2000 and was completed on August 3, 2000. Building-by-building disinfection refers to the disinfection of the individual plumbing systems for each building connected to the water supply system. (Reference should be made to Section 10.0 of the OCWA Report for a full description of this program.)

The building-by-building disinfection initiative was designed and implemented by OCWA and its agents in conjunction with its watermain flushing and swabbing program. The distribution system was divided into 11 sections to facilitate the disinfection procedures.

In Walkerton, there were 1,816 connections to the distribution system to be disinfected. These represented approximately 2,300 residences and businesses. For each building connected to the system, the disinfection program entailed a two-day process.

On the first day, disinfection crews visited a building and proceeded to flush all taps, fixtures and water-using appliances with highly chlorinated water (a chlorine residual of at least 200 mg/L was used). Fixtures were then locked shut and tagged. Crews moved on to the next building leaving the chlorinated water in the building's plumbing system for a minimum of 12 hours to provide complete disinfection.

On day two, crews returned and determined that an adequate level of residual chlorine (> 50 mg/L) remained in the building's plumbing system. Crews untagged the disinfected fixtures, flushed them once more and dechlorinated the water using sodium thiosulphate (a chlorine neutralizing agent). The dechlorinated water was discharged into the sewer system.

The first buildings to be disinfected were the four public and private institutions served by the Ministry's alternate water supply initiative. A detailed discussion of the procedures implemented under the alternate water supply program is provided in Appendix C.

In its report, OCWA states that:

- by August 3, 2000, the building-by-building disinfection program was completed, with 1,816 separate buildings disinfected; and
- every plumbing system of every building connected to the municipal water distribution system was disinfected, including plumbing fixtures, appliances and other systems that made use of the municipal water supply.

Given its scope and complexity, this building-by-building disinfection program stands as one of the most comprehensive municipal water supply disinfection programs undertaken in Ontario.

Watermain Replacement

As mentioned earlier, all watermains greater than 100 mm were swabbed. Swabbing attempts were made on the 100 mm watermains, but they were found to have a significant build-up of calcium, magnesium and iron carbonate deposits, which prevented effective swabbing. In some areas, this build-up had reduced the effective capacity of these pipes by 50 percent. OCWA's microbiological consultant advised that, while the flushing of watermains less than 100 mm in diameter had effectively cleaned and disinfected those sections, the biofilm contained within the 100 mm pipes could harbour contaminants.

On July 24, 2000, the Ministry ordered the Municipality and the PUC to replace these sections of 100 mm watermain (see Figure 1). Following discussions with the Municipality and the PUC, OCWA arranged for and managed the pipe replacement process. (Reference should be made to Section 9.0 of the OCWA Report for a full description of this work.)

REPLACED WATER MAINS

FIGURE 1

WATER MAIN REPLACEMENT PROGRAM

In its report, OCWA states that:

- approximately five kilometres of the existing 100 mm watermain, which had accumulated a significant amount of mineral encrustation and was, therefore, not able to be cleaned by swabbing and flushing, was eliminated from the water distribution system;
- 150 mm diameter polyvinyl chloride (PVC) pipe was installed to improve the capacity of the water system to carry flows for fire protection and minimize the future development of sediments, mineral encrustation and biofilm in the distribution system;
- the work included the replacement or extension of 215 residential water service connections with PVC pipe, which is more resistant to biofilm growth; and
- in some instances, the existing service connections were found to be connected with a plug fitting rather than by a tapped and threaded connection and these were replaced with a tapped fitting to improve the safety and security of the system.

Ministry Assessment of OCWA's Restoration Program

Watermain Flushing and Standpipe Cleaning

OCWA's flushing and standpipe cleaning operations in Walkerton were conducted in accordance with MOE *Procedure B13-3*, which refers to the American Water Works Association (AWWA) Standard C651-99 *Disinfecting Watermains* and MOE Bulletin 65-W-4 *Chlorination of Potable Water Supplies*.

Elimination of Watermain Dead Ends

OCWA is currently maintaining the system through a program of weekly flushing at selected dead ends. While this is an effective means of maintaining the distribution system, it is very labour intensive. Eliminating dead ends and low flow areas should be considered as part of a long-term system maintenance strategy. With better flow through the distribution system, chlorine residuals can be maintained at the required levels to prevent bacterial growth.

Watermain Swabbing

The Ministry required swabbing as an additional precaution to provide for the removal of material build-up within the watermains that could harbour bacteria and protect them from chlorination.

While the swabbing program was underway, there were increased levels of coliform and heterotrophic bacteria populations in the system due to biofilm material from the inner surface of the watermains being dislodged. The swabbing program removed a great deal of the biofilm and sediment from the system.

Building-by-Building Disinfection and Flushing

OCWA developed its protocol for the Building-by-Building Disinfection Program in discussion with the Ministry.

The Ministry conducted a Disinfection Audit in conjunction with OCWA's Building-by-Building Disinfection Program. The Ministry also implemented a Building-by Building Sampling Program in order to confirm that the plumbing in every home and business in Walkerton was disinfected. Detailed discussions of these programs follow later in this part of the report.

Watermain Replacement

The design and construction of the watermain replacement work was carried out by a consulting engineer to meet the requirements of the Ministry guidelines and Ontario Provincial Standards Specification (OPSS) 701.

The Ministry issued a Certificate of Approval for the replacement of watermains on August 9, 2000. In addition to approving the main replacement, the Ministry required, as a condition of the approval, that the PUC develop a work plan to monitor chlorine residuals in the watermain and undertake preventive swabbing or flushing to clean the watermains.

In accordance with OPSS 701 requirements, all completed watermains were swabbed, pressure tested and disinfected before they were connected to the distribution system.

MOE's Sampling and Audit Programs

Throughout the restoration work, the Ministry conducted extensive audit and sampling programs to ensure that the Ontario Drinking Water Standards (ODWS) were satisfied.

The audit and sampling programs that are described in the following sections include:

- an audit of the Building-by-Building Disinfection process established by OCWA to disinfect the plumbing of buildings that were connected to the water supply system;
- the Building-by-Building Sampling Program that was carried out to verify that every building within Walkerton had been successfully disinfected;
- a Post-Restoration Sampling Program that assessed several key aspects of the distribution system, once the summer's restoration work had been completed; and
- an audit and assessment of OCWA's Distribution System Sampling Program.

The results from the various programs were compared to the standards contained within ODWS, particularly the microbiological parameters and the chemical parameters relating to chlorination. These parameters are summarized briefly below.

Total coliforms are a long standing indicator of drinking water quality. Their presence in a distribution system is considered indicative of inadequate disinfection, the presence of an established biofilm and/or the introduction of particulate matter (e.g. soil particles) into a system.

Total coliforms are assessed through either a Presence/Absence (PA) test that will indicate the presence of total coliforms in the sample, or a Membrane Filtration (MF) test that gives an estimate of the number of total coliforms that are present. PA results are reported simply as Present or Absent. MF tests are reported as the number of Colony Forming Units (CFU) per

100 ml of sample. In ODWS, the standard for total coliforms in treated water is 0 CFU /100 ml. Positive Total Coliform PA tests or MF results greater than 0 CFU /100 ml are described as adverse results.

Escherichia coli or *E. coli* are coliform bacteria that are a strong indication of recent fecal (human or animal waste) pollution. *E. coli* are rapidly destroyed by chlorine and its presence in the distribution system is indicative of a failure in disinfection or the intrusion of contaminated water after treatment. The ODWS standard for *E. coli* in treated water is 0 CFU /100 ml. Positive *E. coli* PA tests or MF results greater than 0 CFU /100 ml are described as adverse results.

If *E. coli* are detected in repeat samples in the distribution system, a serious breakdown in disinfection has likely occurred.

The **Heterotrophic Plate Count** (HPC) is an estimate of the number of background bacteria present in the distribution system. HPC is not an indicator of fecal contamination, but is a more general indicator of disinfection effectiveness and distribution system status with respect to biofilm presence and the influence of bacterial regrowth in the distribution system. Rapid changes in previously stable HPC results are often precursors to adverse coliform results. The ODWS standard for HPC in treated water is less than 500 CFU /ml. HPC results greater than 500 CFU /ml are described as adverse results.

Many types of coliforms are not associated with fecal contamination and some may be present in the biofilm that occurs in most distribution systems. Studies have shown that most water distribution systems have an annual total coliform frequency of 0.1 – 1.0%[3] and that summer months typically produce more (up to 5%) samples positive for total coliforms because of biofilm growth.[4]

In interpreting bacteriological results, one must recognize the variability that is inherent in any sampling and analytical methodology. The Ministry's laboratory analysed samples using PA, MF and HPC methodologies (MOE methods WQPA-E3226, MicroMFDC-E3407A and MICROSPP-E3408, respectively).

In the validation of the MF method[5], a confirmation rate of 96.4% for total coliforms and 97.2% for *E. coli* was obtained. Although the confirmation rates for these two parameters are less than 100%, the probability of a false positive is less than 5%. Consequently, there may occur an occasional adverse result in a distribution system which may not be observed in a repeat sample. In assessing the data collected through the various audit and sampling programs, the sample results were interpreted based on trends over time or by locations.

In addition to the three microbiological parameters specified in Ontario's standards, the **Total Aerobic Spore** count (TAS) was evaluated during the Disinfection Audit. Aerobic spores are considered to be much more resistant to disinfection by chlorination than are most other bacteria. While there are no specific standards for TAS, GAP (OCWA's microbiological consultants) advised that significant reductions in TAS levels from samples taken after disinfection, compared to those observed in the raw water, would provide an overall measure of the effectiveness of disinfection.

In addition to monitoring for the microbiological parameters, ODWS specifies that a level of chlorine be maintained in the distribution system. This residual chlorine discourages the regrowth of bacteria after the water has been disinfected at the source. Chlorine present in the distribution system as hypochlorous acid (HOCl) or the hypochlorite ion (OCl^-) is referred to as the Free Chlorine Residual. Chlorine that has reacted with ammonia to form chloramines is referred to as the combined chlorine residual. The sum of the free chlorine residual and the combined chlorine residual is reported as the total chlorine residual. ODWS states that the minimum free chlorine residual in a water distribution system should be 0.2 mg/L. The maximum free chlorine residual should be less than 4.0 mg/L in the distribution system.

MOE's Disinfection Audit

In order to obtain an early indication of the effectiveness of OCWA's building-by-building disinfection process, the Ministry implemented a comprehensive Disinfection Audit. The audit was based on the collection and testing of samples from approximately one in every three of Walkerton's estimated 1,816 connections to the distribution system.

After the disinfection of a building had been completed, the Ministry visited the premises and collected and tested water samples taken from kitchen taps or other taps used for drinking water. Each residence and building that was audited was sampled for total coliforms, *E. coli*, TAS and HPC.

Analyses for total coliforms and *E. coli* were performed by the Ministry laboratory, which is accredited by the Standards Council of Canada to conduct these analyses. Samples were analysed using the membrane filtration technique. Samples were also collected and sent to GAP's laboratory for TAS analysis.

Any locations that had adverse test results for total coliforms or *E. coli* were sampled a second time. If the second sample was also adverse, the Ministry's protocol called for the building disinfection to be repeated.

Results

A total of 683 samples, including 15 follow-up samples for total coliform and 1 follow-up TAS sample, were taken from 667 locations. The results are presented below.

Table A: Summary of Disinfection Audit Samples with Adverse Results

683 Samples	Total Coliforms (> 0 CFU /100 ml)	*E. coli* (> 0 CFU /100 ml)	HPC (> 500 CFU/ml)
Percent Adverse	2.2%	0%	0%
Number Adverse	15	0	0

E. coli were not detected in any of the 683 samples. No HPC sample results were found to exceed the criteria. Fifteen samples, or 2.2 percent of the total number of samples, tested positive for total coliforms. All of the locations that tested positive for total coliforms were

resampled and none of the subsequent samples had adverse results.

GAP EnviroMicrobial Services assessed the TAS data. They found that, "*the most important finding is that these extremely chlorine-resistant spores have been reduced to low levels with only a few exceptions.*"[6]

One sample had a high TAS count (>2,400 CFU/500 ml), but no total coliforms or *E. coli*. The result of a follow-up sample at this location was 0 CFU /500 ml for TAS.

Summary

Ministry staff audited the performance of OCWA's building-by-building disinfection program by sampling for total coliforms, *E. coli*, HPC and TAS at every third building that had been disinfected.

The very low number of positive results for Total Coliforms tests (2.2%) is well within the expected range. None of the sites tested positive in repeat sampling. No *E. coli* were detected in any of the samples.

GAP found that the level of reduction in TAS after disinfection suggests that the survival of *E. coli* in the distribution system or on biofilm surfaces is highly unlikely and in particular, it is unlikely that any *E. coli* O157:H7 or *Campylobacter* survived the swabbing and chlorination regime.[7]

Based on the results of the Ministry's Disinfection Audit, the Ministry is satisfied that OCWA's building-by-building disinfection process was effective in disinfecting the plumbing in Walkerton's buildings and residences.

For additional information on the Ministry's Disinfection Audit, please see Appendix D.

MOE's Building-by-Building Sampling Program

The primary objective of the water supply restoration program was to disinfect the water distribution system of any remaining *E. coli* O157:H7 or *Campylobacter*. The Ministry's Disinfection Audit showed that OCWA's disinfection process was effective in disinfecting the plumbing of individual buildings. Promoting public confidence in the restoration of the water supply, however, was another important objective. To meet this objective, the Ministry wanted to demonstrate that every home and every building in the community had been disinfected.

Sampling of individual homes and businesses began at least two weeks after the buildings in each area of Walkerton were disinfected. The minimum two week waiting period was imposed to allow for the recovery and detection of any bacteria that might have survived the disinfection process.

Samples were taken from the kitchen tap, or the tap most commonly used for drinking water purposes. The samples were analysed for *E. coli*, total coliforms, including background and HPC at Lakefield Research Laboratories Ltd., a Standards Council of Canada accredited

facility.

If the results from a sample exceeded zero for total coliform or *E. coli.*, the site would be resampled on two subsequent days. In addition, a program criterion of 250 CFU/ml was chosen for HPC, which is one-half the level in the ODWS. Given the extensive restoration that had been carried out in the distribution system, any result above this level would be considered unusual and worthy of follow-up sampling.

If either of the two follow-up samples had adverse test results, the building disinfection process would be repeated. This cycle would continue until the building was disinfected and the sample results met the ODWS.

Results

Between July 27, 2000 and October 4, 2000, sampling teams went to each residence and building in Walkerton. A total of 2,607 samples were collected. The results are presented in summary below and in detail in Appendix E.

Table B: Summary of Building-by-Building Sampling Program Samples with Adverse Results

2607 Samples	Total Coliforms (>0 CFU /100ml)	*E. coli* (>0 CFU /100ml)	HPC (>250 CFU/ml)	Background (>200 CFU/ 100ml)
Percent Adverse	1.2%	0.04%	0.4%	0.08%
Number Adverse	30	1	10	2

E. coli, not 0157:H7, were detected (2 CFU/100 ml) in only one sample, on August 14, 2000. This was confirmed through subsequent analysis of the August 14, 2000 sample, which did not detect the presence of *E. coli* 0157:H7. This site was resampled twice (August 16, 2000 and August 18, 2000) and both follow-up samples were negative.

The follow-up samples for the thirty adverse total coliform samples tested negative. All ten of the follow-up HPC test results were less than 250 CFU/ml.

The ranges in the bacterial test results were exceptionally low. No total coliforms were detected in 98.8 percent of the samples (2577 of the 2607 tests). Ninety-one percent of the HPC tests were reported as less than 10 CFU /ml, the detection limit for the method.

Summary

Following OCWA's building-by-building disinfection of the distribution system, the Ministry sampled every home and building served by the Walkerton water supply system. The results of the samples were compared to the ODWS. In all cases, the results met the criteria established and the houses and buildings were considered to be disinfected.

Based on the results of the Ministry's Building-by-Building Sampling Program, the Ministry is satisfied that OCWA's building-by-building disinfection program was effective in disinfecting the plumbing systems of the buildings within Walkerton.

For a more detailed explanation of the Ministry's Building-by-Building Sampling Program, please see Appendix E.

MOE's Post-Restoration Sampling Program

By September 2000, the bulk of the disinfection and restoration work on the distribution system had been completed. On August 24, 2000, OCWA began reducing the chlorine dosage at the wells towards a normal operating level. This eventually resulted in a decrease in the average free chlorine residual in the distribution system from approximately 2.5 mg/L to 1.0 mg/L.

During September and October 2000, the Ministry undertook an intensive round of sampling of the distribution system. This work was conducted in three phases, as follows:

- Between September 5, 2000 and October 1, 2000, the number of locations sampled by the Ministry each day in the distribution system was expanded from two to twenty-one.
- On September 12, 2000, additional samples were taken at each of the above locations and submitted to the Ministry of Health and Long-Term Care Laboratory to be tested for *Campylobacter* and *Salmonella*.
- On October 2, 2000, samples were collected from forty-eight sites throughout the distribution system (including the raw and treated water at Well 7) to test the water quality in the areas near sensitive receptors.

The results of that work are described in the following section.

Distribution System Sampling

The Ministry collected 621 samples from twenty-one locations in the distribution system and from the raw and treated water at Well 7 between September 5, 2000 and October 1, 2000 (Well 6 was not in use during this period). These samples were taken at the same sampling locations that were used in the routine Distribution System Sampling Program (see Figure 3, page 20). Samples were analysed for total and free chlorine residuals, as well as total coliforms, *E. coli* and HPC.

The results of the bacteriological testing are presented in the following table.

Table C: Summary of Adverse Bacteriological Results in the Post-Restoration Sampling Program

Sample Location	No. of Samples	Total Coliforms (>0 CFU /100 ml)	*E. coli* (>0 CFU /100 ml)	HPC (>500 CFU/ml)
Distribution System	567	5 (0.88%)	0	0
Well 7, Raw Water	27	11 (41%)	0	0
Well 7, Treated Water	27	0	0	0

The results from the distribution system and the treated water from Well 7 consistently showed very low levels of total coliforms (greater than ninety-nine percent were 0 CFU /100ml) and HPC (one hundred percent were less than 10 CFU/ml). No *E. coli* were detected in any of the samples taken. The maximum level of total coliforms measured in the distribution system was 12 CFU /100 ml.

The daily total coliform levels in Well 7's raw water were 0 CFU /100 ml from September 5, 2000 to September 20, 2000. Between September 21, 2000 and October 1, 2000, positive total coliforms were detected in the raw water on each day at levels ranging from 2 - 22 CFU /100ml.

The onset of the total coliform occurrences coincided with the replacement of the pump at Well 7. On September 20, 2000, the turbine pump that normally services the well failed because of a bent shaft. The pump was removed for repair and replaced with a standby submersible pump of the same capacity.

The average free chlorine residual level in the distribution system on September 5, 2000 was 1.9 mg/L. By October 1, 2000, the average free chlorine residual had been reduced to 1.1 mg/L (see Figure 2).

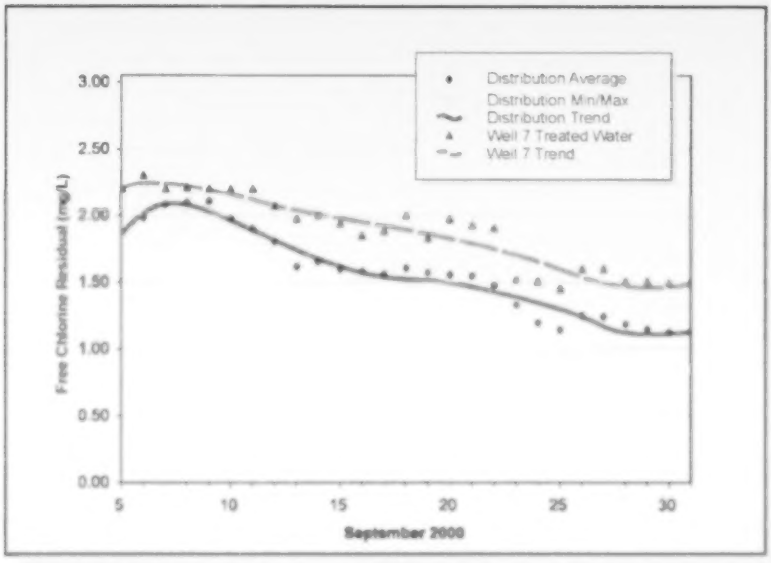


Figure 2: Free Chlorine Residual Trends at Well 7 and in the Distribution System during September 2000

The increase in the chlorine residuals observed at the beginning of September is from the increase in chlorine dosage in response to the adverse results of August 27, 28, 2000 and of September 2, 3, 2000. (For a discussion of the results of August 27, 28, 2000 and September 2, 3, 2000, see Appendix G-2). Once testing from the Distribution System Sampling Program showed no total coliforms or *E. coli* in the system, OCWA again began reducing the chlorine dosage at Well 7. As the dosages at the well were reduced, the free chlorine residual in the distribution system also declined. By the end of the month, the levels had begun to stabilize, with no further adverse results in the distribution system.

Campylobacter and *Salmonella* Testing

In its epidemiological investigation[2], the Bruce-Grey-Owen Sound Health Unit reported that three different pathogenic bacteria were present in samples from patients during the outbreak; *E. coli* O157:H7, *Campylobacter* and *Salmonella*.

On September 12, 2000, the Ministry collected twenty-three additional samples at the normal distribution system sample sites. These samples were submitted to the Ministry of Health and Long-Term Care's laboratory in Toronto for analysis for *Campylobacter* and *Salmonella*.

No *Campylobacter* or *Salmonella* were detected in any of the samples.

Sensitive Sites Testing

On October 2, 2000, samples were collected by the Ministry from throughout the distribution system to test the water quality in the areas where watermains were replaced, or near sensitive

sites.

Total and free chlorine residuals were monitored. Samples were collected for bacteriological analyses at each location. Where possible, the samples were collected from a tap used to supply the premises with potable water, typically the kitchen sink.

Forty-six locations in the distribution system were chosen for this sample collection program. They were selected for the reasons described in Appendix F and reflected at least one of the following:

- located near possible sensitive sites; (hospital, senior citizens' homes, public schools, etc.);
- adverse results detected previously;
- watermain dead ends;
- areas where the 100 mm mains had been replaced; or
- areas of low free chlorine measurements determined from previous surveys.

In addition, the raw and treated water from Well 7, the only well in production at the time, was also sampled. The samples were analysed by Lakefield Research Laboratories, a Standards Council of Canada accredited laboratory, for total coliform, *E. Coli* and HPC, using membrane filtration.

Duplicate samples were taken at six of the distribution system sites for audit purposes and sent to the Ministry laboratory for analysis.

The analysis did not show the presence of any *E. coli* or total coliforms. The highest HPC was 35 CFU/ml. The six samples taken for audit purposes also showed no adverse results.

Summary

Three different test programs were conducted during September and early October 2000, to assess the post-restoration status of the distribution system. These programs included an expansion of the Ministry's Distribution System Sampling Audit (discussed in the next section of this report), specific sampling for two pathogenic bacteria (*Campylobacter* and *Salmonella)* that were identified during the outbreak, and an assessment of sensitive sites in the distribution system.

The samples were taken as the system was being brought into its normal operating range with respect to chlorination. By October 5, 2000, chlorine dosage at the well and free chlorine residuals in the distribution system had stabilized.

No *E. coli*, *Campylobacter* or *Salmonella* were detected in the samples collected. Total Coliform and HPC monitoring results were indicative of excellent water quality.

The results of the Post-Restoration Sampling Program confirmed the results of the previous Disinfection Audit and Building-by-Building Sampling Program, namely, that OCWA's restoration program was effective in disinfecting the distribution system and building plumbing. The restoration program carried out by OCWA has resulted in the elimination of any pathogens, including *E. coli O157:H7*, *Salmonella* and *Campylobacter*,

in the distribution system.

The results also confirmed that the water in the distribution system meets all of the bacteriological standards defined in the ODWS.

For additional information on the Ministry's Post-Restoration Sampling Program, please see Appendix F.

MOE's Distribution System Sampling Audit

The Ministry's Distribution System Sampling Audit was implemented to verify the results of daily system sampling undertaken by OCWA.

In response to the outbreak, the Ministry began sampling Walkerton's water supply on May 22, 2000. On June 30, 2000, the Ministry modified its daily sampling program to provide a quality assurance measure for OCWA's distribution system sampling program.

The Ministry collected samples at six of OCWA's sampling locations on at least three days each week, analysing for total coliform, *E. coli*, HPC and TAS. Two of these samples were taken from varied locations throughout the distribution system to audit the sampling of the twenty-one OCWA sampling stations. The other four samples were raw and treated water taken from both Wells 6 and 7.

Results

To assess OCWA's distribution system sampling program, Ministry data and OCWA data were paired by date and by location. The Ministry then statistically analysed the data to determine if any significant difference existed between the Ministry's data and that collected by OCWA. If the results were found to be comparable, then the Ministry would use the OCWA database to assess the condition of the water supply system.

The results for total coliforms and free chlorine residuals were found to agree at a ninety-five percent level of confidence. All paired *E. coli* results were 0 CFU /100 ml. The majority of the HPC results were below the level of detection of <10 CFU /ml (96% in the MOE data set, 77% in the OCWA data set). Because of these high levels of non-detections, no statistical analysis was carried out.

Based on the Ministry's Distribution System Sampling Audit, the Ministry is satisfied that OCWA's data for total coliforms and free chlorine residual is comparable to that of the Ministry's, and therefore, is an accurate reflection of the quality of the water in the distribution system.

For additional information on the Ministry's Distribution System Sampling Audit, please see Appendix G.

OCWA's Distribution System Sampling Program

In order to monitor the ongoing microbiological quality of the Walkerton water supply and to comply with a Ministry order, OCWA initiated a comprehensive distribution system sampling program on May 29, 2000. Twenty-one strategically located sampling stations were selected throughout the community for daily sampling (see Figure 3). In addition, untreated and treated water from each well in production was sampled daily.

The sample locations used by OCWA were selected to meet a variety of criteria. The locations were dispersed throughout the distribution system to provide for complete coverage. Two locations were selected where the water supply from the wells enters the distribution system. Samples were also taken in the vicinity of both standpipes. The other sample locations were selected based on historical information, including the locations of known dead-ends.

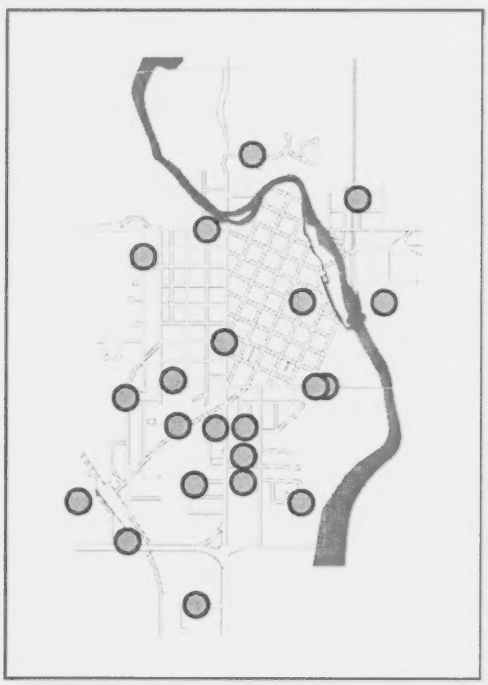


Figure 3: Distribution System Sampling Sites

Between June and October 2000, OCWA's monitoring data showed:

Table D: Summary of Adverse Total Coliform Results in OCWA's Distribution System Sampling Program.

Time Period	No. of Samples	No. of Adverse Total Coliform Samples	Frequency of Adverse Total Coliform Samples
June	630	50	7.9%
July	652	26	4.0%
August	651	65	10%
September	630	12	1.9%
October	630	8	1.3%

The number of adverse results for total coliforms fell between May 25, 2000 and mid-June in response to the flushing of the distribution system, the cleaning of the standpipes and the increase in chlorine dosage at the wells.

In mid-June, the frequency of adverse total coliforms results suddenly increased. This increase was attributed to the initiation of OCWA's swabbing of the distribution system on June 11, 2000, which resulted in fragments of the biofilm being dislodged within the distribution system.

No total coliforms were detected in OCWA's samples from the end of the swabbing program in mid-July until early August. Starting in the second week of August, OCWA began experiencing a number of low level, sporadic adverse results (geometric mean 5 CFU /100 ml). This trend culminated on the weekend of August 27, 2000, when almost half of the distribution samples showed the presence of total coliforms.

An examination into the high number of positive total coliforms was undertaken by both OCWA and the Ministry. Based on that examination, it would appear that surface water impact on Well 6 contributed to the contamination of the system. In addition, some of the adverse results were likely associated with contaminants introduced during sampling. The investigation is discussed further in Appendix G-2.

On August 29, 2000, OCWA removed Well 6 from service. Since that time, the number of adverse total coliform results has dropped to between one and two percent. This is well within the expected range for a normal distribution system. The following table shows the number of adverse total coliform results segregated by time period.

Table E: Summary of Adverse Total Coliform Samples for Selected Time Periods relating to OCWA's Restoration Activities.

Time Period	No. of Samples	No. of Adverse Total Coliform Samples	Frequency of Adverse Total Coliform Samples
June 11 - July 10 (Watermain swabbing)	603	66	10.9%
July 11- August 29 (Wells 6 & 7 operating)	1,032	73	7.1%
Aug. 30 - Oct. 31 (Well 7 operating)	1,492	22	1.5%

E. coli were detected in the distribution system five times between June 1, 2000 and the end of October, 2000. The samples showing two positive results from September 2 and 3, 2000 were further tested for the presence of *E. coli* O157:H7. GAP reported that the *E. coli* were non-pathogenic. Follow-up testing at the same locations by both OCWA and MOE did not find any *E. coli*. A Ministry sample in late October also tested positive for *E. coli*. Eighteen subsequent resamples over the next two days were all clear and further testing of the original sample confirmed that there was no *E. coli* O157:H7.

The HPC results were variable and probably reflective of a distribution system with an established biofilm under the stress of flushing, swabbing and elevated chlorine levels.

The chlorine dosage at the wells was increased so that by mid-June the average free chlorine residual in the distribution system was greater than 1.5 mg/L. Although OCWA reports that the chlorine dosage remained constant from June until the end of August, the average free chlorine residual in the distribution system increased to greater than 2.5 mg/L in August.

In late August, OCWA began reducing the chlorine dosage at Wells 6 and 7. The dosage was increased in response to the adverse Total Coliform results of August 27 and 28, 2000. In September, OCWA again began reducing the chlorine dosage at Well 7, the only well in production (Well 6 had been shut down on August 29, 2000). By early October, the average free chlorine residual in the distribution system had stabilized at approximately 1 mg/L. Free chlorine residuals in the distribution system ranged from 0.6 to 1.5 mg/L.

Summary

Between May 28, 2000 and October 31, 2000, OCWA conducted an intensive monitoring program of the Walkerton water supply system. Over 3,000 samples were collected and analysed for total coliforms, *E. coli*, Heterotrophic Plate Count and free chlorine residuals.

The results of the distribution system sampling program supports the conclusion that the water quality of the Walkerton distribution system meets the *Ontario Drinking Water Standards*.

The Ministry will work with OCWA and the PUC to develop and implement a comprehensive sample program that will be required on an ongoing basis through the Walkerton water supply system's Certificate of Approval.

FIGURE 4 | WALKERTON MUNICIPAL WELLS

PART THREE: SECURITY OF WALKERTON'S WATER SUPPLY

While Part Two of this report has confirmed that OCWA's restoration program, including the disinfection of each building's plumbing, effectively disinfected the water supply system, the security of the system is an integral part of a safe water supply for Walkerton.

This part of the report discusses the following key elements underlying the security of Walkerton's water supply system:

- OCWA's program to eliminate cross-connections (e.g. private wells and cisterns) to the municipal water system and the need to ensure that no new cross-connections are made.
- Upgrades to the water system.
- The integrity of each well and test well that is a part of the municipal water supply system.
- The implementation of filtration treatment for Wells 6 and 7, based on information provided in the OCWA Report and the PUC's *Walkerton's Future Water Supply Study, Interim Report - Short-term Supply* (RVA Study).

Two additional Ministry sampling programs are also discussed in this part of the report. The first program was undertaken to confirm that the filtration system is effective in treating the water from Wells 6 and 7. It is referred to as the Filtration System Sampling Program. The second sampling program provides a chemical characterization of the water supply from Wells 6 and 7 and in the distribution system.

Cross-Connection Elimination

Cisterns and private wells in Walkerton presented a potential for the introduction of untreated water into Walkerton's water supply distribution system. If, for any reason (e.g., a watermain rupture) the pressure in Walkerton's water supply system became lower than the pressure in a private system, water from the private system could be drawn into Walkerton's supply through cross-connections.

The use of cisterns as a source of soft water was widespread in Walkerton because of the hardness of the water supply. In addition to the 474 cisterns, there were also 39 properties with private wells, many of which were in use as the sole source of water or in conjunction with the municipal water supply system.

On June 23, 2000, the Walkerton PUC passed a by-law banning residential cross-connections and requiring approval for cross-connections in any commercial operations. The bylaw led to an initiative to separate all unapproved cross-connections in the community as part of OCWA's overall restoration program.

The work was completed by private plumbers on behalf of OCWA. In a number of cases, the private water supply system was abandoned entirely and replaced by water softening equipment supplied to the property owner. In most cases, it was necessary to carry out a

physical separation of the two systems by severing pipe connections or installing taps with separate faucets.

OCWA reported that these measures removed the risk of contamination of the municipal water supply from these sources. All cisterns and private wells were inspected and have been disconnected or are separate from the municipal water supply system.

Ministry Assessment

OCWA's results and conclusions are consistent with Ministry field observations and information on cross-connections gathered through the Ministry's Building-by-Building Sampling Program and an audit carried out by the Ministry. The results of this audit can be found in Appendix E of this report.

A public education and enforcement program should be undertaken by the Municipality and the PUC to support the by-law restricting cross-connections to the municipal water supply, to ensure that new cross-connections are not created.

The Ministry is satisfied with OCWA's conclusion that the cross-connection elimination program was successful in removing the risk of cross-connection contamination of the municipal water supply by private sources.

Standard Operating Procedures and Monitoring Equipment

After OCWA assumed operational responsibility for the Walkerton water supply system on May 25, 2000, it began a program to upgrade the water supply system equipment and operational procedures to improve the security of the system. (Reference should be made to Section 5.0 of the OCWA Report for a description of these upgrades.) The following summarizes the system upgrades implemented by OCWA, including repairs to pumphouse equipment, the installation of monitoring and alarm systems, and the development of new Standard Operating Procedures (SOPs).

OCWA developed a series of twenty-one SOPs for the Walkerton water supply system to provide an operational protocol to ensure a consistent response to contingencies and daily operating procedures. These SOPs deal with areas such as well, pump and standpipe operations, equipment operation, sampling requirements for both chemical (chlorine) and bacteriological analyses, and contingency plans for operations and adverse sampling results.

Two free chlorine residual analysers were initially installed at Well 6 and 7, containing alarm systems which were capable of shutting down the pumps in the event that the free chlorine residual dropped below a programmed set point. These have now been replaced by a single analyser that has been incorporated into the filtration system (described further in this part of the report). This free chlorine residual analyser is also equipped with an alarm system which will shut down the filtration system in the event that the free chlorine residual drops below a programmed set point and transmit an alarm signal to the OCWA's Southampton Hub.

The filtration system is fully automated and has the ability to shut down the system in case of an alarm condition that is detrimental to the equipment. The filtration system is equipped with an on-line particle counter which monitors treated water on a continuous basis. If a breach of a membrane should occur, the particle counter will detect it and shut down the filtration system and transmit an alarm signal to the OCWA's Southampton Hub.

Free chlorine residual analysers have been installed at the two standpipes and in the treated water line prior to the entry of the water to the distribution system. All of the free chlorine residual analysers are of the continuous monitoring type and are equipped with alarms that will trigger when free chlorine residual falls below a predetermined level.

The free chlorine residual analyser data from the two standpipes, treated water line and the filtration system are transmitted via an FM signal to OCWA's Southampton Hub where the data are monitored and recorded on a continuous basis.

OCWA also took immediate steps to address the fact that Well 7 is an artesian well, which flows even when the pump is not in service. This flow is directed to the outside of the pumphouse, through a new overflow pipe equipped with a back flow prevention device.

A still well, equipped with a water level sensing device, was installed near the discharge of the overflow pipe. In the event that water levels in the adjacent wetland reach levels that could pose a flood threat to the well head, an alarm is activated which shuts down the pump and notifies OCWA's Southampton Hub. Restarting the pump requires a site visit by an operator and a manual reset of the pump control.

At both Wells 6 and 7, continuous turbidity analysers have also been installed on the pump discharge. These data are also transmitted to the Southampton Hub.

Reporting of data, events and alarms is done through OCWA's computer monitoring system, Outpost 5™, which records data and events and allows for analysis. Any alarmed process at the Walkerton site is monitored and recorded by that system.

Ministry Assessment

The measures taken by OCWA to install a new overflow pipe and back flow prevention device were an appropriate interim step to secure Well 7. As noted in the *Well Integrity* section of this report, however, the Ministry will require that the overflow pipe at the well be permanently removed.

OCWA's upgrades to the monitoring equipment and operational procedures of the Walkerton water supply system provide important safeguards for the security of the water supply. The Ministry will require that these, or similar systems, be maintained on a continuing basis.

Walkerton Wells - Well Integrity

Hydrogeological Report on the Security of Walkerton's Wells

The information provided is primarily based on Golder's May 31, 2000 Preliminary Assessment, its August 18, 2000 Interim Report, and its Final Report completed on September 18, 2000. Each of these reports was submitted to comply with a Ministry order.

Golder's preliminary assessment discussed the hydrogeological conditions of Wells 5, 6 and 7. Its Interim Report provided information on well inspections, well integrity testing, geophysical surveys, land use inventory and the bacteriological impacts on the Walkerton town wells.

The Final Report provided the results of Golder's investigation into the hydrogeological conditions in the area of Wells 5, 6 and 7. The work included a detailed groundwater investigation in the area of the wells. At the request of the Ministry, Golder repeated a tracer test on Well 5 on September 19, 2000. The Final Report was supplemented by an addendum on September 21, 2000 reporting on the repeated tracer test.

A map showing the locations of Walkerton's wells is included as Figure 4.

Non-production Wells - Wells 1, 2 and 3

The PUC owns wells that are not normally used to produce water for the community. As part of its overall assessment, Golder undertook an assessment of Wells 1 and 2 and recommended they be properly plugged and abandoned.

Golder indicated that Well 3 produces water of relatively good chemical quality, but that it is not routinely operated as part of the system because of its limited production (400 litres per minute, or 588,000 litres per day).

Golder also indicated that the well is located at the lower slope of a farm field, a short distance from a cattle operation. When they inspected the well, it was apparent that runoff had deposited sediment around and in the pump house.

While the well casing appeared to be well bonded (sealed) throughout its length, Golder recommended that discontinuities (potential holes) in the well should be further examined if it is to be used again.

Ministry Assessment: Wells 1, 2 and 3

Well 3 is connected to the distribution system between Wells 6 and 7 and the main part of Walkerton (see Figure 4). Therefore, water from the well could have entered the distribution system without having been treated by the filtration treatment system. The Ministry, therefore, requested that Well 3 be disconnected from the distribution system. The pump has been removed from the well, creating a physical separation between the well and the distribution system.

The Ministry will require that:

- former production Wells 1 and 2 be properly abandoned and plugged in accordance with Ministry guidelines and O. Reg. 903;
- if the PUC plans to use Well 3 again, it investigate and, if necessary, repair the casing, modify the drainage patterns surrounding the pumphouse so that overland run-off cannot enter or wash against the building, and assess the need for further treatment beyond disinfection;
- if it is determined that Well 3 will not be used again, it abandon and plug the well in accordance with Ministry guidelines and O. Reg. 903;

The locations of Wells 1, 2 and 5 are shown in Figure 5.

Well 5

In its hydrogeological assessment for Well 5, Golder indicated that:

- Well 5 taps a shallow bedrock aquifer which is overlain by an overburden with a thickness of as little as 2.4 metres at the well site;
- Test Wells 1 and 2 (TW1 and TW2), located near Well 5, were found to be in a poor state of repair and represented potential entry points for contaminants from surface water to the supply aquifer ;
- Well 5 is located within a few metres of farm fields which are subject to fertilization with manure and the application of farm chemicals; and
- upon pumping the well, water ponded in the immediate area of the well was observed to rapidly infiltrate the ground, a nearby spring stopped flowing, and water flow from the spring reversed back into the spring.

Based on its investigations, Golder concluded that the shallow aquifer tapped by Well 5 at this location could not be made adequately secure and should no longer be used as a source of public supply. Golder also stated that, in its opinion, Well 5 was not secure, nor could it be made adequately secure, from potential impacts. As a result, Golder recommended that Well 5 be properly plugged and abandoned. Test Wells 1 and 2 were also plugged and abandoned in accordance with Ministry guidelines, at Golder's direction.

Ministry Assessment: Well 5

Well 5 was taken out of production on May 23, 2000. On June 9, 2000, the Ministry issued an Order to the Municipality requiring that Well 5 remain closed and disconnected from the Walkerton water supply system. The well was physically disconnected on June 21, 2000.

As part of the overall work to secure Walkerton's water supply, the Ministry will require that Well 5 be abandoned and plugged in accordance with Ministry guidelines and O. Reg. 903.

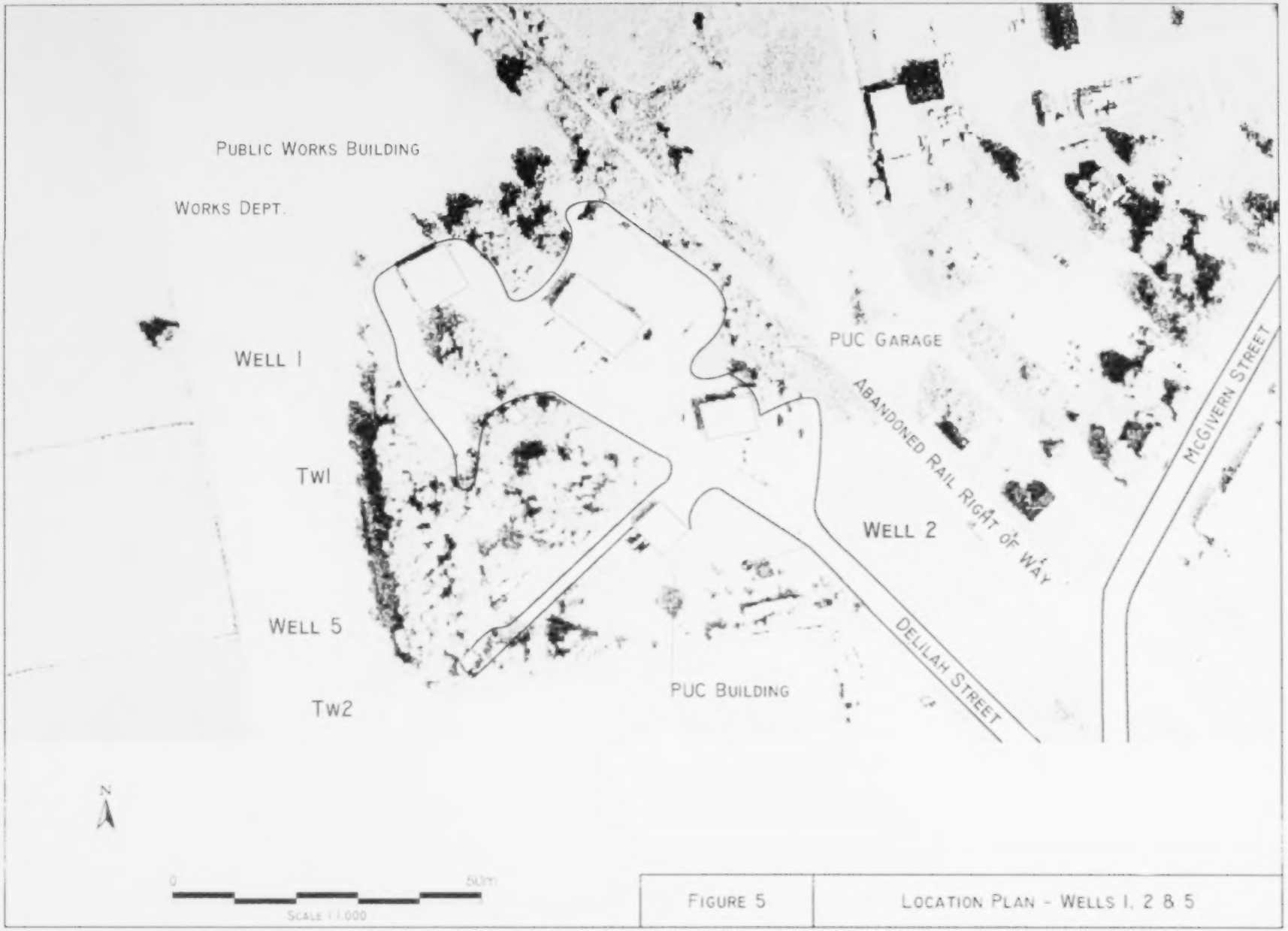


FIGURE 5 | LOCATION PLAN - WELLS 1, 2 & 5

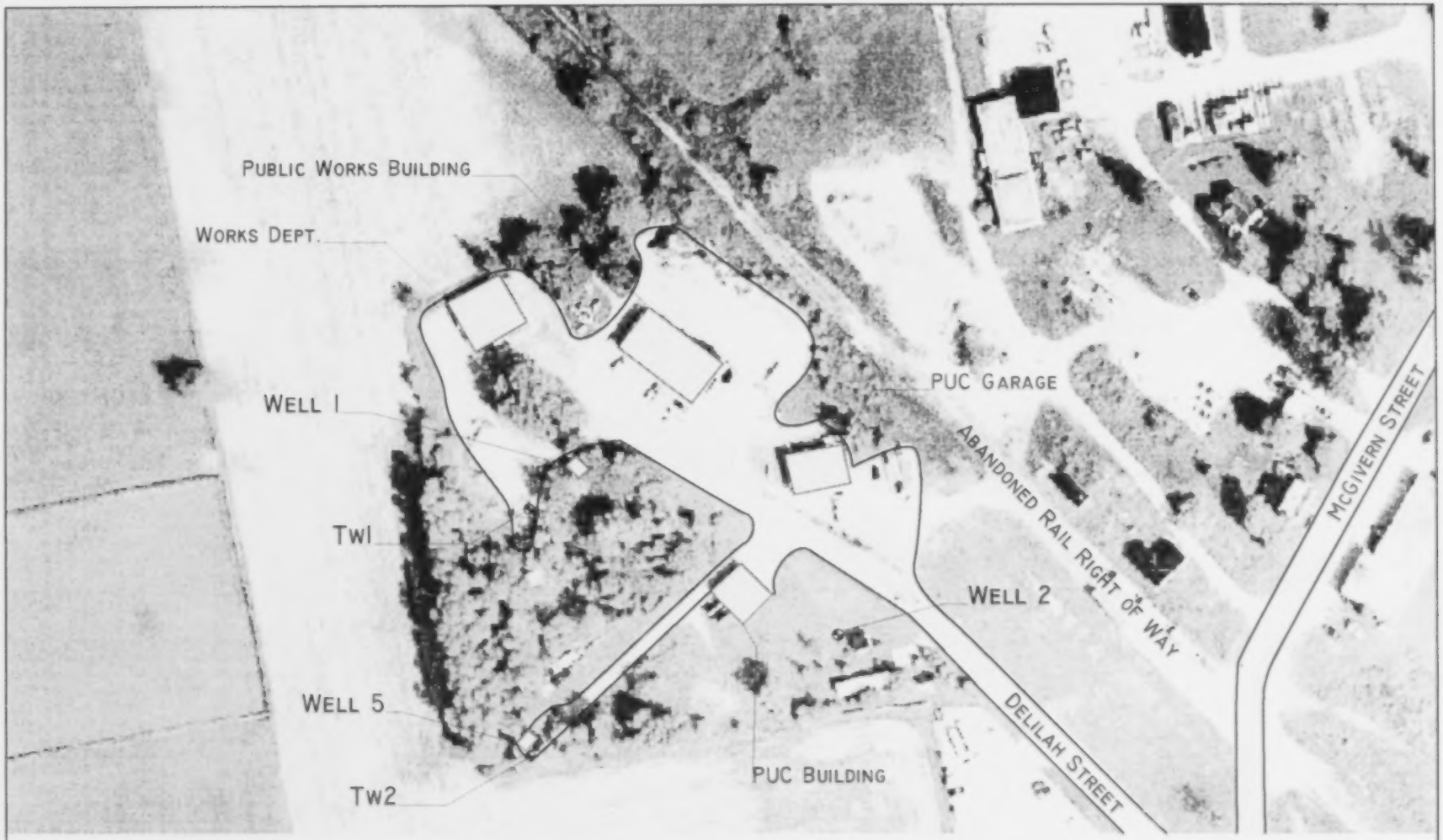


FIGURE 5 | LOCATION PLAN - WELLS 1, 2 & 5

Well 6

Golder's Interim Report indicated that:

- Well 6 (see Figure 6) obtains water from seven different producing zones, with half its water coming from a depth of 19.2 metres;
- the chemical quality of the water is generally good, but varies with depth;
- elevated nitrate levels and hardness, as well as variable iron and turbidity were observed;
- with one exception, bacteriological analysis indicated no contamination of these water producing zones at the time of sampling; and
- there are four fabricated penetrations (holes) in the well casing within 1.25 metres of the base plate at the top of the casing.

Golder's Final Report indicated that:

- Well 6 obtains much of its water from intermediate depth water producing zones which have been shown to be hydraulically connected to surface water in the nearby wetland and to a nearby private pond;
- it was not conclusively demonstrated that the hydraulic connection is the reason for the occasional presence of bacteria in the well water; and
- one or more of the casing penetrations identified above the water level in the well could account for the occasional presence of bacteria.

Golder recommended that:

- the casing penetrations be investigated and plugged;
- down hole testing be carried out to determine which water producing zones are more directly hydraulically connected to surface water;
- the Well 6 casing be extended to seal off the shallow fractures that are hydraulically connected to surface water; and
- the Municipality establish a well head protection area (WHPA) around the well field and develop appropriate land use management practices for the long-term protection of both the WHPA and the catchment area to protect the well's water supply.

Further work was recommended by Golder for test wells TW1-82 and TW2-82 close to Well 6.

Ministry Assessment: Well 6

At Well 6 there is a potential for direct access of surface water into the well. The groundwater supply for this well may also be under the direct influence of surface water.

The Ministry will require that the Municipality develop and implement a well head protection program in the well field area and conduct appropriate repairs/rehabilitation to Well 6 and its nearby test wells TW1-82 and TW2-82.

The Ministry recommends that the pond identified as being hydraulically connected to the water producing zones of Well 6 be filled with material of low permeability.

FIGURE 6 | LOCATION PLAN - WELLS 6 & 7

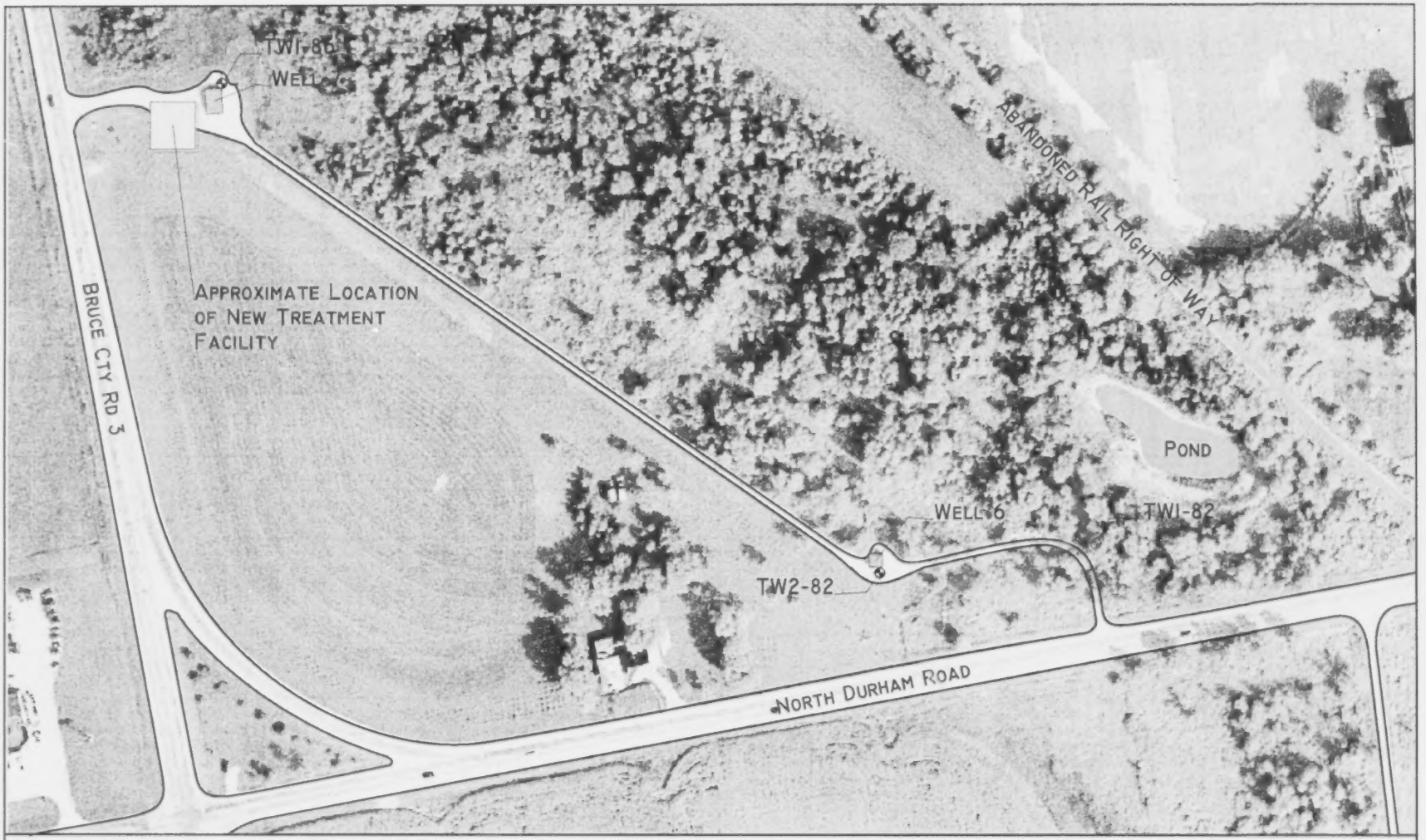


FIGURE 6 | LOCATION PLAN - WELLS 6 & 7

Since:

- **there is a potential for direct access of surface water into the well;**
- **the groundwater supply for the well may be under the direct influence of surface water; and,**
- **there is no well head protection program currently in place,**

the Ministry concludes there is a need for filtration of this water supply.

As part of this assessment, the Ministry has also considered the report entitled *Walkerton Future Water Supply Study, Interim - Short Term Supply* (September 2000) by R.V. Anderson Associates Limited (RVA). This report recommended that the filtration system be implemented for Wells 6 and 7 and that other measures be further studied and applied. These measures include additional upgrades and repairs to Wells 6 and 7 and the surrounding test wells. The work plan developed for these upgrades also includes the development of additional firm water supply capacity in the Well 6 and 7 area.

With regard to the further work recommended for Well 6 and the test wells mentioned above, the Ministry will require that this work be carried out based on the work plan set out in Appendix A of the RVA study, or as otherwise revised and approved by the Ministry.

Well 7

Golder indicated that Well 7 has a static water level above ground level. When this well is not being pumped, it overflows via an overflow pipe equipped with a back flow prevention device, into the adjacent wetland.

Golder's Interim Report indicated that:

- testing identified three water production zones with most water coming from between 52 and 73 metres below ground;
- the water quality in Well 7 during testing was good, both from a chemical and bacteriological perspective;
- testing indicates that the casing is well grouted; and
- there is one area of corrosion which should be investigated further.

Golder stated that, with the recommended repairs to nearby test well TW1-86 and the repairs to the corrosion on the Well 7 casing, the well appears to be a secure groundwater supply.

Golder's Final Report stated that Well 7 is considered a much more secure water supply than Well 6, primarily because it obtains its water from producing zones at greater depth, below 45.7 metres. In fact, half of the water is produced from a zone below a depth of 72.4 metres near the bottom of the well.

Aquifer testing by Golder showed some hydraulic connection between Well 7 and Well 6 and, therefore, to groundwater in the overburden. However, the results of chemical and bacterial

analyses of samples from both wells show that the chemical and bacteriological water quality at Well 7 is superior to that at Well 6.

Golder recommended that:

- the Well 7 overflow pipe be disconnected and the casing penetration be sealed;
- that a small area of suspected casing corrosion in the well be investigated and corrected;
- the Municipality establish a well head protection program around the well field (combining both wells 6 and 7) and develop appropriate land use management practices for the long-term protection of this area to protect the municipal water supply; and
- test well TW1-86, adjacent to Well 7 be properly grouted, following its completion as a multi-level monitoring well.

Ministry Assessment: Well 7

Golder provided no explanation for the adverse bacteriological results reported for Well 7 by the PUC in May 2000. Samples taken on May 15, 2000, by the PUC at Well 7 showed results of: Total coliforms > 200 CFU/100 ml; *E. coli* > 200 CFU/100 ml; and HPC = 600 CFU/ml. Results during later testing consistently showed no *E. coli*. Daily monitoring by both OCWA and the Ministry has shown that, while occasional Total coliforms are detected in the raw water, they are generally at low levels.

Based upon four months of daily monitoring since the May 15, 2000 adverse results were reported and the fact that Well 7 is considered a much more secure water supply, it appears that the sample that day is not representative of the groundwater from Well 7.

The shallow overburden and the fractured limestone that represents the bedrock in the area of Well 7 combine to create a relatively vulnerable water supply. To address this, the Ministry will require the Municipality and PUC to develop and implement a well head protection program to protect the quality of its water supply.

In the hydrology assessment of the area surrounding Well 7, submitted as part of the Municipality's October 2000 *Report on Cause*, Stantec Consulting Limited concluded that the overflow pipe from Well 7 could have been inundated by runoff conditions which resulted from the heavy rainfall reported on May 12, 2000. This conclusion suggests that measures are needed to eliminate any potential that the well head area could be flooded.

Upon assuming responsibility for the operation of the system, OCWA upgraded the Well 7 overflow pipe by replacing the overflow pipe extending from the pumphouse pad to the point of discharge, installing a new back flow prevention device, and installing a high water level alarm. This was an appropriate short-term measure. However, the overflow pipe should be disconnected from Well 7 and the casing penetration sealed.

As there is some hydraulic connection between Wells 6 and 7, the Ministry concludes that there is a need for filtration treatment at Well 7.

The Ministry will require that:

- **the overflow pipe for Well 7 be removed and the resulting casing penetration sealed;**
- **the repair and upgrades to Well 7 and Test Well TW1-86 be carried out in accordance with the work plan set out in Appendix A of the R. V. Anderson study, or as otherwise revised and approved by the Ministry;**
- **the Municipality implement a plan to prevent the possible flooding of the well head areas, without affecting the functions of the wetland;**
- **that the plan be to the satisfaction of the Ministry or as otherwise required; and**
- **the Municipality and the PUC develop and implement a well head protection program in the area of Wells 6 and 7.**

The Ministry will also require that the monitoring wells installed as part of the hydrogeological work be abandoned and plugged in accordance with Ministry guidelines and O. Reg. 903, unless they are needed for future purposes.

Filtration Treatment

Based on the information provided in the reports submitted to the Ministry and the assessment of this information, a need for treatment at Wells 6 and 7 has been identified. Due to the potential access of surface water to these wells, especially Well 6, the level of treatment required for these raw water sources to ensure a safe supply that meets the ODWS, is filtration and disinfection, such as chlorination.

This treatment will allow the work that has been identified in the RVA study to further secure these well areas to be completed over a longer period. A municipal well head protection program could also be implemented during this time. The future assessment of this well head area, including the future treatment necessary for Walkerton's long term water supply, will form part of the long term work identified in the RVA study.

It should be noted that the RVA study will evaluate other options that could be used to provide safe, reliable drinking water to Walkerton for the long term. Some of the options under consideration are: pipeline connection from the Great Lakes through an area water supply scheme; alternate treatment processes (using the existing wells); development of a new well field, etc. The study will proceed under the requirements of the **Environmental Assessment Act**, as required.

The double barrier of filtration and chlorination at Wells 6 and 7, therefore, will supply Walkerton's water. On September 21, 2000 the PUC authorized OCWA to complete the design and carry-out construction of the new 5,000 m^3/day capacity filtration system.

The filtration system consists of hollow-fibre ultrafiltration modules that form a barrier to particulate matter such as cysts (*Giardia/Cryptosporidium*); bacteria (coliforms) which are greater than 0.1 micron in size. Since cysts and bacteria are generally larger, they are effectively removed.

The filtered water is pumped to a storage tank called a clearwell, where chlorine is added. The clearwell is designed to retain the water to provide for adequate time (minimum of 15 minutes) for disinfection to occur. There is continuous monitoring for turbidity and chlorine residual on the treated water prior to it being pumped into the distribution system.

MOE's Filtration System Sampling Program

During the commissioning of the treatment system in late October and early November 2000, a sampling program was conducted at strategic points in the new treatment system and the distribution system.

Samples were collected of the raw, filtered and treated (filtered and chlorinated) water during the one day of testing for each of Wells 6 and 7 (see Figure 7). Duplicate samples were taken nine times a day and analysed for the ODWS bacteriological parameters. In addition, samples were collected for *Campylobacter* and *Salmonella* analysis of the raw and treated water.

Samples were also collected at each location for general water chemistry analysis (hardness, alkalinity, pH, nitrogen, conductivity, etc.).

Once the bacteriological results were received indicating the treatment system was producing water of high quality, the filtered water from Well 7 was directed into the distribution system. Over the next five days, samples were collected at the treatment system, at the entry to Walkerton and in the distribution system at the twenty-one routine distribution system sampling sites (see Figure 3, page 20).

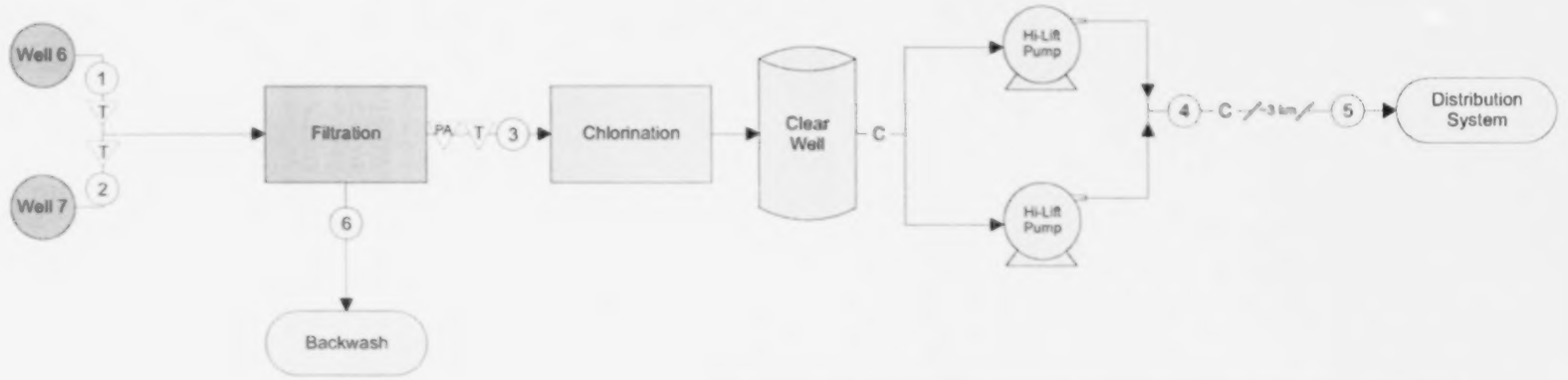
Results

Filtration System Sampling

A summary of the results of the tests of the filtration system using Well's 6 and 7 are presented below. The testing program was conducted at Well 7 while the water was chlorinated; therefore, the quality of the water being sampled as treated water is the quality expected to be delivered to Walkerton.

Table F: Summary of Adverse Bacteriological Results from the Filtration System with Well 7 as the source water supply.

Sample Location	No. of Samples	Total Coliforms (>0 CFU/100 ml)	*E. coli* (>0 CFU/100 ml)	HPC (>500 CFU/ml)
Raw Water	18	7	0	0
Post Filtration	18	0	0	0
Treated Water	18	0	0	0



Legend

Sampling Location

Online Analyser

1: Well 6 Raw Water
2: Well 7 Raw Water
3: Post-Filtration
4: Post-Chlorination
5: Distribution System
6: Filter Reject Water (Backwash)

C: Free Chlorine Residual
PA: Particle Size
T: Turbidity

Figure 7

Treatment System
Process Schematic and Sample Locations

Figure 7	Treatment System Process Schematic and Sample Locations

The testing program conducted at Well 6 did not have any chlorine added to the system and depended solely on filtration to remove bacteria.

Table G: Summary of Adverse Bacteriological Results from the Treatment System with Well 6 as the source water supply.

Sample Location	No. of Samples	Total Coliforms (>0 CFU/100 ml)	*E. coli* (>0 CFU/100 ml)	HPC (>500 CFU/ml)
Raw Water	18	17	0	0
Post Filtration	18	0	0	0
Treated, Un-chlorinated Water	18	0	0	1

Total coliforms were detected in 17 of the 18 raw water samples taken at Well 6 and in 7 of 18 samples collected at Well 7. The sample results from each of the wells showed no total coliform or *E. coli* in either the filtered or treated water samples. One sample result for HPC had a value of 1,000 CFU/ml. A duplicate sample, taken at the same time and location, showed a value of less than 10 CFU/ml. The data are shown in detail in Appendix H-1.

None of the eight samples collected during the filtration system testing showed the presence of either *Campylobacter* or *Salmonella* (see Appendix H-2).

Water Chemistry

The chemical analyses of the water collected during the filtration system testing showed that the water quality met all health related drinking water standards, but exceeded the operational guideline for hardness. The chemistry data are contained in Appendix H-3 and a full evaluation of water chemistry characterization is contained in Appendix I.

Distribution System Sampling Program

The results of the five day sampling program from November 6 to 10, 2000, in the distribution system and at the filtration system are in Appendix H-4 and are summarized below in Table H:

Table H: Summary of Adverse Bacteriological Results from the Distribution System while Filtration was in Operation - November 6 - 10, 2000.

Sample Point	No. of Samples	Total Coliforms (>0 CFU/100 ml)	*E. coli* (>0 CFU/100 ml)	HPC (>500 CFU/ml)
Raw Water	19	12	0	0
Treated Water	19	0	0	0
Distribution System	124	0	0	1

During this survey two samples had background levels above 200 CFU /100ml and one sample showed an adverse HPC (630 CFU/ml.) Results of the Membrane Filtration tests for these same samples, however, did not indicate the presence of total coliforms or *E. coli*. The sites were re-sampled and no total coliforms or *E. coli* were present. On the resamples, all of the HPC results were less than 10 CFU/ml, the detection limit for the method.

During the same time period of November 6 to 10, 2000, the samples collected by OCWA at the same locations in the distribution system showed no adverse results.

Conclusions

The testing of the treatment system using water from Wells 6 and 7 found that the treated water met ODWS. The treatment plant provides an effective double barrier to bacterial contamination, delivering high quality drinking water to the residents of Walkerton.

MOE's Chemical Characterization of the Water Supply

A program was initiated to characterize the chemical quality of the Walkerton water supply and to compare it with ODWS. All chemical, physical and bacteriological parameters identified in the ODWS were analysed and assessed.

Raw water samples collected from Well 6 and raw and treated water samples from Well 7 were analysed for all ODWS parameters, including; total nitrates, fluoride, arsenic, lead, pesticides and trihalomethanes (THM). These samples were also tested for aesthetic and operational guidelines, such as; colour, hardness, sodium and iron. In addition to Wells 6 and 7, water samples were taken at 16 distribution system locations and analysed for specific parameters.

Drinking Water Surveillance Program sampling protocols, which are summarized in Appendix I, were followed so that all samples were collected in a similar manner. The sample lines at Well 6 and 7 were flushed for a minimum of five minutes prior to sample collection, so that water standing in the line was not sampled. At all 16 distribution system locations, a free flowing sample was taken. The free flow sample represents fresh water sampled from the distribution system watermain.

Summary

The analytical results for all of the ODWS parameters are presented in Appendix I. The results for selected health-related chemical parameters are summarized below:

Table I: Summary of Selected Health-related ODWS Parameters

Parameter (Health Related)	ODWS Parameter (mg/L)	Minimum Result (mg/L)	Average Result (mg/L)	Maximum Result (mg/L)	No. of Samples
Total Nitrates *(as nitrogen)*	10	1.27	1.53	4.92	18
Fluoride	1.5	0.22	0.68	0.75	18
Arsenic	0.025	not detected	0	0.0002	18
Lead	0.01	0.00012	0.00062	0.0039	18
Pesticides	Variable[a]	< MDL[b]	< MDL[b]	< MDL[b]	6
Trihalomethanes	0.100[c]	< 0.0005	0.0026	0.0095	20

Notes:

[a] For specific pesticide standards and descriptions, please refer to ODWS.

[b] MDL represents the Method Detection Limit, which indicates the minimum level that a parameter can be measured by the analytical instrument. The method detection limits for all pesticides tested were well below the ODWS for each pesticide.

[c] This standard is expressed as a running annual average of quarterly samples measured at a point reflecting the maximum residence time in the distribution system.

The chemical quality of the Walkerton water supply met the ODWS requirements for all health related parameters. Total nitrates, fluoride and arsenic were found to be below their respective drinking water standards. Furthermore, no pesticides were detected. Metals such as lead, copper and iron were also well below their respective standards.

THM is the most widely occurring disinfection by-product found in chlorinated drinking water. THM was examined due to the relatively high chlorine residual levels (greater than 1.5 mg/L) in the distribution system. Although THM was observed in all 16 distribution water samples, the concentrations were well below the ODWS standard.

The results for selected aesthetic or operational parameters such as colour, hardness, sodium, copper and iron are summarized below:

Table J: Summary of Selected Aesthetic and Operational ODWS Parameters

Parameter (Aesthetic or Operational)	ODWS Parameter	Minimum Result	Average Result	Maximum Result	No. of Samples
Colour	5 TCU[d]	< 0.2	0.68	6[e]	18
Hardness (as $CaCO_3$)	80 to 100 mg/L	370	386	434	18
Sodium	200 mg/L[f]	4.8	5.8	17.6	18
Copper	1.0 mg/L	0.0011	0.011	0.037	18
Iron	0.30 mg/L	0	0.009	0.037	18

Notes:

[d] True Colour Units

[e] One result for Well 6 was 6 TCU. Further sampling during the filtration plant commissioning confirmed results for colour in the 1.6 to 1.8 TCU range (see Appendix H) which meets the ODWS.

[f] The aesthetic objective for sodium in drinking water is 200 mg/L. ODWS recommends that the local Medical Officer of Health be notified when the sodium concentration exceeds 20 mg/L so that this information may be communicated to local physicians for their use with patients on sodium restricted diets.

The drinking water objectives for all aesthetic and operational parameters outlined in the ODWS, with the exception of hardness, were met. The operational guideline for hardness is 80 to 100 mg/L. Hardness above 200 mg/L is considered poor but tolerable; above 500 mg/L, the water is considered unacceptable for most domestic purposes. The average hardness level was found to be 386 mg/L as calcium carbonate ($CaCO_3$).

Based on the results of Ministry's chemical characterization sampling program, the Ministry is satisfied that the water quality meets the ODWS requirements for all health related chemical parameters.

CONCLUSIONS

This report examines the actions taken by the Municipality and the PUC to restore and secure the Walkerton water supply and distribution system after the May/June 2000 outbreak of gastroenteritis in the Walkerton area, caused by *E. coli* O157:H7 and *Campylobacter* bacteria.

As a result of the outbreak, the Medical Officer of Health for Bruce-Grey-Owen Sound issued a Boil Water Advisory for Walkerton residents on May 21, 2000. The next day the Ministry was asked to investigate the operation and security of the water system.

On May 25, 2000, the Ministry issued its first in a series of orders to the Municipality and the PUC setting out the actions necessary to restore and secure the Walkerton water supply system. The Bruce-Grey-Owen Sound Health Unit's epidemiological report on the outbreak showed that contamination was widespread throughout the municipal water distribution system, confirming the need for the extensive remediation program that has been undertaken in Walkerton.

The following outlines the final conclusions of the Ministry's report:

Restoring the Distribution System

The program to clean and disinfect the distribution system was completed by OCWA and its agents, on behalf of the Municipality and the PUC. OCWA reported that:

- the water distribution system was completely flushed, effectively removing bacteria and loose sediment from the system;
- Walkerton's two water storage facilities (standpipes) were completely cleaned and disinfected, addressing any concerns with bacteria in the standpipes;
- dead end locations which might have remained contaminated if left unchecked were identified, fitted with fire hydrants, or blow off lines and flushed, or disinfected during the building-by-building disinfection process;
- thirty-one kilometres of large diameter pipes were swabbed a minimum of four times, effectively removing and reducing accumulated biofilm from these pipes;
- the plumbing in each of the 1,816 separate buildings in Walkerton was disinfected, including traditional plumbing fixtures, appliances and other systems that made use of the municipal water supply;
- five kilometres of 100 mm watermains, which could not be swabbed because of a build-up of oxidation and hard water scale were replaced; and
- an extensive water sampling and testing program was undertaken to confirm the effectiveness of the disinfection and restoration activities.

In order to confirm the effectiveness of OCWA's disinfection and restoration program, the Ministry completed extensive audit and sampling programs, resulting in the testing of over 5,000 water samples.

These audit and sampling programs included:

- a Disinfection Audit to determine the effectiveness of OCWA's building-by-building disinfection program, based on 683 samples,
- a Building-by-Building Sampling Program to confirm that the plumbing in every home and business in Walkerton was disinfected, based on 2,607 samples;
- a Post-Restoration Sampling Program to test Walkerton's water quality upon the completion of OCWA's summer restoration work (including the pipe replacement program) based on 698 samples; and
- a distribution system sampling program to audit and confirm OCWA's sampling results and to monitor the ongoing microbiological quality of the water supply system.

Based on the results of the Ministry's audit and sampling programs, the Ministry concludes that:

- **OCWA's restoration program was successful in disinfecting the distribution system and the plumbing in all buildings and residences of Walkerton, resulting in the elimination of any pathogens, including *E. coli* O157:H7, *Salmonella* and *Campylobacter* bacteria;**
- **the water in the distribution system meets all bacteriological parameters defined in the *Ontario Drinking Water Standards*.**

The Security of Walkerton's Water Supply

Actions taken to secure the water supply focussed on the integrity of Walkerton's wells, upgrades to the PUC's operational procedures and monitoring equipment, the elimination of cross-connections to the municipal water supply and the implementation of filtration and chlorination treatment for Wells 6 and 7.

The Elimination of Cross-Connections

OCWA reported that all cisterns (474) and 39 properties with private wells were examined and disconnected, as required, from the municipal water supply system as part of its extensive cross-connection elimination program.

OCWA's results and conclusions are consistent with Ministry field observations and audit on cross-connections gathered through the Ministry's Building-by-Building Sampling Program. All known cross-connections between private water systems and the municipal distribution system have been eliminated.

The Ministry is satisfied with OCWA's conclusion that the cross-connection elimination program was successful in removing the risk of cross-connection contamination of the municipal water supply, adding to the security of the system. Ongoing municipal public education and enforcement of the PUC's by-law banning residential cross-connections will be essential.

Operational Procedures and Monitoring Equipment

OCWA has undertaken an extensive program of upgrades to the water supply system, including the installation of continuous chlorine and turbidity analysers and monitoring and alarm systems that report on system activity.

OCWA also developed a series of standard operating procedures to deal with equipment operation, sampling requirements for both chemical (chlorine) and bacteriological analyses, and contingency plans for operations and adverse sampling results.

The Ministry is satisfied that the upgrades to the monitoring equipment and operational procedures of the Walkerton water supply system provide safeguards for the security of the water supply.

Wells 1, 2 and 3

Un-maintained former production wells represent a threat to the security of an aquifer. Improperly sealed casings and/or casing penetrations represent a direct route for surface water access to the water supply aquifers.

In order to ensure that these wells are secured, the Ministry will require that Wells 1 and 2 be plugged and abandoned. Well 3 has been disconnected from the distribution system pending a decision on its future use as part of the RVA study.

Well 5

Well 5 was taken out of production on May 23, 2000. On June 9, 2000, the Ministry issued an Order to the Municipality requiring that Well 5 remain closed and disconnected from the Walkerton water supply system. The Ministry will require that Well 5 be permanently abandoned and plugged.

Well 6

The Ministry concludes that there is a potential for direct access of surface water into the well and that the groundwater supply for this well may be under the direct influence of surface water.

The implementation of filtration and chlorination treatment at Well 6 is required to bring the system into compliance with the *Ontario Drinking Water Standards* and Procedure B13-3, *The Chlorination of Potable Water Supplies in Ontario*.

Longer-term rehabilitation will require repairs to, and possible further capacity development of, Well 6 and adjacent test wells, the filling of an adjacent pond and a well head protection program.

Well 7

Well 7 exhibits the best raw water quality, both microbiologically and chemically, of the Walkerton wells. Based on findings of some hydraulic connection between Wells 6 and 7, the

implementation of the filtration and chlorination treatment at Well 7 is also necessary. A municipal well head protection program will also be required.

Repairs to the well, including the removal of the existing overflow pipe and repairs to adjacent test well TW1-86 will be required to further protect Well 7 as a secure source of groundwater. Further capacity development in the Well 7 area will also be examined as part of the R. V. Anderson study.

Filtration Treatment for Wells 6 and 7

The implementation of the filtration and chlorination treatment system for Wells 6 and 7 will provide an effective double treatment barrier to secure the water supply. Ministry sampling has confirmed the system's effectiveness in delivering water that meets the *Ontario Drinking Water Standards*.

Chemical Characterization

Finally, the Ministry's chemical characterization of Walkerton's water supply, compared to the parameters set out in the *Ontario Drinking Water Standards*, clearly shows that the water quality meets all *Ontario Drinking Water Standards* parameters, with the exception of hardness, an operational guideline.

Summary

In summary, based upon the information received pursuant to Ministry Orders and the Ministry's own monitoring data, the Ministry is satisfied that the restoration work carried out in Walkerton has brought the water supply system into compliance with the *Ontario Drinking Water Standards*.

The Ministry will continue its work with the Municipality of Brockton and the Walkerton Public Utilities Commission to ensure the implementation of the follow-up actions identified in the report.

GLOSSARY OF TERMS

Aerobic Bacteria - bacteria that require oxygen for growth and can grow under an air atmosphere (21% oxygen).

Aesthetic- aspects of drinking water quality (namely taste, odour, colour and clarity) that are perceivable by the senses.

Annular Space - the space created between the outside diameter of well casing and the inside diameter of the hole drilled for the well.

Background - when used in reference to a total coliform membrane filtration test, background colonies are the non-coliform colonies. Excessive numbers of background colonies can interfere with the ability of coliforms to produce colonies or characteristic reactions, leading to an under reporting of the coliforms.

Bacteria - a group of diverse and ubiquitous procaryotic single-celled organisms.

Biofilm - microbial cells attached to pipe surfaces forming a film or slime layer on the pipe. Biofilm is of concern because it can harbour and protect coliform bacteria from disinfectants as well as imparting objectionable tastes and odours.

Cone of influence - the area surrounding a well where the water table would drop as a result of water pumping from the well.

Contamination - the introduction of materials which makes otherwise potable water unfit or less acceptable for use.

Conventional Filtration - a mode of water treatment to remove particles which consists of coagulant addition, rapid mixing, coagulation, flocculation, sedimentation and filtration.

Corrosion - in the context of drinking water distribution, corrosion is the deterioration and leaching of metal from a pipe surface as a result of its reaction with the aquatic environment.

Cryptosporidium - a protozoan parasite that produces an environmentally stable oocyst that is highly resistant to disinfection, but can be removed by effective treatment, which includes filtration.

Disinfection - effective destruction by chemical or physical processes of non-spore forming organisms capable of causing disease. Spore forming bacteria and parasitic cysts are usually resistant to traditional methods of disinfection (i.e., chlorination).

***Escherichia coli* (*E. coli*)** -*E. coli* is a fecal coliform bacterium and can be detected using membrane filtration or presence/absence methods.

Since *E. coli* is present in fecal matter and prevalent in sewage and animal feces, it is a specific indicator of recent fecal pollution.

Contamination with sewage as shown by positive *E. coli* tests would strongly suggest presence of pathogenic bacteria and viruses, as well as more chlorine resistant pathogens such as *Giardia* and *Cryptosporidium* which are much more difficult to detect.

***E. coli.* O157:H7** - is a strain of *E.coli* bacteria which produces potent toxins known to attack kidney cells, called *verotoxins*. *E. coli* O157:H7 have been shown to cause haemolytic ureamic syndrome (kidney damage) and haemorrhagic colitis (bloody diarrhea) in humans. It is highly infectious, in doses as low as 10 to 100 cells.

Fecal coliforms - the fecal coliform group are a portion of the coliform group that is capable of fermenting lactose at 44 ° to 45 °C within 48 hours. The presence of fecal coliforms in drinking water is indicative of contamination with human or animal waste.

Escherichia coli is the fecal coliform most frequently associated with recent fecal pollution. The presence of fecal coliforms in drinking water is a strong indication of contamination with human or animal waste.

Filter - a porous media through which a liquid may be passed to effect removal of suspended materials. The filters used in the membrane filtration assessment of coliforms have a pore size of 0.45 µm (0.00002 inches).

Firm Capacity - the ability of a water supply system to meet its needs with the largest source of supply (e.g. the largest well) out of service.

Giardia - small, flagellated, protozoan parasites that inhabit the small intestines of a variety of animals. Giardia is the most commonly reported intestinal parasite in North America causing nausea, diarrhea, an uneasiness in the upper intestine, malaise and perhaps low-grade fevers and chills. A well-managed water treatment system providing effective filtration and disinfection should control contamination by *Giardia*.

Groundwater - water located in the saturated zone of the earth's crust.

Heterotrophic Plate Count (HPC) - The heterotrophic plate count is a method of measuring the aerobic bacterial content in water. Samples are incubated for 48 hours on a selected nutrient at 35° Celsius. Levels of bacteria detected by the test should not exceed 500 colonies per ml sample. HPC testing can be used to monitor disinfection efficiency at water treatment plants and to measure water quality deterioration in distribution systems and in reservoirs.

Hydrogeological - related to the science of groundwater, its occurrence, movement and chemistry.

Hydrology - science of surface water, its occurrence, movement and chemistry.

Incrustation - deposition of a crust or hard coating on a surface.

Membrane Filtration (MF) - a method for the enumeration of bacteria in water. A measured volume of water is filtered through a sterilized membrane which is then transferred to the surface of an appropriate agar medium and incubated. Upon incubation, retained bacteria give

rise to visible colonies on the membrane surface.

Microorganism - a microscopic organism that cannot be seen without the aid of a microscope, including bacteria, protozoa, fungi, viruses and algae.

NTU (Nephelometric Turbidity Unit) - Unit of measure for turbidity in a water sample.

OPSS 701 - Ontario Provincial Standards Specification (OPSS) requirements for installing watermains, service connections and other structures, devices and appliances (e.g., valves) which are used in conjunction with a water distribution system.

Pathogen - an organism capable of causing disease symptoms in another organism.

pH - index of hydrogen ion activity, pH is defined as the negative logarithm of hydrogen ion concentration in moles per litre. A solution of pH from 0 to less than 7 is acid, pH of 7 is neutral, pH from above 7 to 14 is alkaline.

Potable Water - water fit for human consumption.

Precipitate - to separate in solid particles from a liquid as the result of a chemical or physical change.

Presence/Absence (P/A) Test - a qualitative procedure used to determine the presence or absence of coliforms in water.

Protozoa - unicellular, non-photosynthetic, nucleated organisms, such as amoebas, ciliates and flagellates.

Raw Water - surface or groundwater that is available as a source of drinking water but has not received any treatment.

Sedimentation - a water treatment process in which solid particles settle out of the water being treated in a clarifier or sedimentation basin.

Spore - resting stage of a simple organism, known to be resistant to chlorine.

Surface Water - water that rests upon the earth's surface.

Treated Water - water entering the distribution system after treatment is complete

Trihalomethanes (THM) - Trihalomethanes are the most widely occurring synthetic organic compounds found in chlorinated drinking water. The principal source of trihalomethanes is the reaction of chlorine with naturally occurring organics (precursors) in the water after filtration. The maximum acceptable concentration for trihalomethanes in drinking water os 0.10 mg/l based on a four quarter moving annual average of test results.

Total Coliforms -The coliform group of bacteria has been the most commonly used indicator of water quality. The coliform group consists of all aerobic and facultatively anaerobic, gram-

negative, oxidase-negative, non-spore forming, rod-shaped bacteria that ferment lactose in a broth medium with gas formation within 48 hours at 35°C. Most coliforms also produce the enzyme ß-D galactosidase which can be detected with a colour forming reagent.

The group generally comprises the genera *Escherichia, Klebsiella, Enterobacter* and *Citrobacter*. The presence of these bacteria in drinking water shows inadequate filtration/disinfection or in the distribution system a continuing loss of the chlorine residual.

Turbidity - Turbidity in water is caused by the presence of suspended tiny particles that scatter light and make the water appear cloudy.

These particles are made from matter such as clay, silt, spores, plankton and other microorganisms. The most important health related effect of turbidity is interference with disinfection and with the maintenance of a chlorine residual. Viable coliform bacteria have been detected in waters with turbidity higher than 3.8 NTU even in the presence of free chlorine residuals of up to 0.5 mg/L and after a contact time in excess of 30 minutes.

Outbreaks of disease traced to chlorinated water supplies have been associated with high turbidity.

The maximum acceptable concentration for turbidity in drinking water is 1.0 Nephelometric Turbidity Unit (NTU) for water entering the distribution system but much lower turbidity around or less than 0.1 are commonly continuously attained in well operated treatment plants. Turbidity measurements are made frequently to confirm the existence of good operating conditions at all surface water treatment plants and at some groundwater plants.

An appearance related aesthetic objective of 5 NTU has been set for water taken at consumers' taps. Turbidity higher than 5 NTU taken at consumer taps generally indicates severe local corrosion and/or poor bacteriological control due to loss of chlorine residual.

ENDNOTES

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Appendix A - Documents Submitted to the Ministry

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The following reports were submitted to the Ministry by the Municipality of Brockton and the Walkerton Public Utilities Commission and were used in the Ministry assessment of the status of the Walkerton water supply system:

- *The Ontario Clean Water Agency's Report to the Walkerton Public Utilities Commission on the Operational Measures Taken to Address the E. Coli Water Contamination in the Town of Walkerton*, The Ontario Clean Water Agency, October 17, 2000.

- *Investigations to Trace the Source of Contamination and Monitor Disinfection of the Drinking Water System in Walkerton, Ontario*, GAP EnviroMicrobial Services Inc. September 29, 2000. (This document is appended to the OCWA Report).

- *Preliminary Hydrogeological Assessment and Recommended Work Plan to Investigate the Source of Bacteriological Impacts, Walkerton Town Wells 5, 6, and 7, Municipality of Brockton, County of Bruce, Ontario*, Golder and Associates Limited, May 31, 2000.

- *Interim Report on Hydrogeological Assessment, Well Integrity Testing, Geophysical Surveys and Land Use Inventory, Bacteriological Impacts, Walkerton Town Wells, Municipality of Brockton, County of Bruce, Ontario*, Golder and Associates Limited, August 18, 2000.

- *Report on Hydrogeological Assessment, Well Integrity Testing, Geophysical Surveys and Land Use Inventory, Bacteriological Impacts, Walkerton Town Wells, Municipality of Brockton, County of Bruce, Ontario*. Golder and Associates Limited, September 2000.

- *Addendum to Hydrogeological Assessment - Bacteriological Impacts, Walkerton Town Wells. Municipality of Brockton, County of Bruce, Ontario*. Golder and Associates Ltd. September 21, 2000.

- *Municipality of Brockton. Contamination of Walkerton Water Supply May 2000: Report on Cause*, B. M. Ross Associates Limited, October 5, 2000.

- *Municipality of Brockton, Walkerton Water Supply Municipal Well #5 Hydrology Report*, B. M. Ross and Associates Limited, October 5, 2000. (This document is appended to the Municipal *Report on Cause*).

- *Walkerton Well # 7 Hydrology Study*, Stantec Consulting Limited, October 2000. (This document is appended to the Municipal *Report on Cause*).

- *Walkerton Public Utilities Commission, Walkerton Future Water Supply Study, Interim Report - Short Term Supply*, Report Number RVA 5446.10, R.V. Anderson Associates Ltd., September 2000.

- *Municipality of Brockton. Contamination of Walkerton Water Supply, Report in Compliance with Section 10 of MOE Field Order NO. F0007721 Issued to the Municipality fo Brockton on May 25, 2000.* B. M. Ross Associates Limited. November 1, 2000.

Appendix B - Ministry Field Orders

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The following is a summary of the Ministry's Walkerton Field Orders.

Field Order F0007721

The May 25, 2000 Order F0007721 required the following actions of the Municipality of Brockton.

It required that the municipality immediately retain the services of a qualified operating authority to oversee the operation and maintenance of the water system to ensure the safety of the drinking water supply.

It required the municipality to submit an action plan by May 26, 2000, including an implementation schedule, for Ministry approval setting out a strategy to:

- thoroughly and completely flush the water distribution system and standpipes with well water from Wells 6 and 7 at a free chlorine concentration greater than 2.0 mg/L; (Amended by Order F0007722 on May 26, 2000 to read: "1.5 mg/L to 2.0 mg/L");
- conduct a monitoring program to the satisfaction of the Ministry for Total coliforms and *E. coli*;
- ensure that the overflow protection at Well 7 will not allow backflow into the system;
- identify all possible contamination sources and ensure that they were not contributing contamination; and
- permanently secure all possible contamination locations.

The Order required that the municipality implement its action plan immediately following Ministry approval.

The Order also required the municipality to determine the possible causes of the contamination of the water system and to submit a report by May 31, 2000 on the water treatment and distribution system for the period from May 4, 2000 leading up to the issuance of the Boil Water Advisory by the Medical Officer of Health on May 21, 2000.

The municipality was also ordered to provide weekly update reports of all actions taken to address the contamination concern.

By June 2, 2000, the municipality was required to submit an action plan to implement continuous, online recording of chlorine concentrations in water from pumphouses 5, 6, and 7 fitted with low level alarms and automatic pump shutoff. The order specified that the municipality was required to implement this plan immediately upon Ministry approval.

The Order also required the municipality to submit an action plan by June 2, 2000, for Well 5 to either install a suitable chlorine contact chamber or an alternate equivalent means for disinfection. The municipality was also ordered to implement this plan immediately upon Ministry approval.

The Order also stipulated that by July 7, 2000, the municipality was required to submit a report documenting the events undertaken to address contamination in the water treatment system

including but not limited to:

- a time line of actions observed and taken;
- all sample analytical results;
- flushing and disinfection procedures; and
- measures to prevent reoccurrence of contamination.

The Order also required that the municipality complete and sign a Report of Compliance indicating the dates that the work ordered was completed, and to notify the Ministry in writing of any significant changes of operation, emissions, ownership, tenancy or other legal status of the facility or operations.

Field Orders F0007723, F0007727 and F0007730

On June 9, 2000, the Ministry issued a second Order to the municipality amending the Order of May 25, 2000.

In the amending order, the Ministry required that Well 5 remain closed and not be returned to service.

It also ordered that, by no later than June 14, 2000, the municipality submit a report for Ministry approval on the status of Well 5 including:

- confirmation, supported by sampling and analysis, that the raw water source is capable of being treated and that through proper disinfection, the water entering the distribution system will meet or exceed the standards set out in the 1994 *Ontario Drinking Water Objectives*; and

- confirmation of adequate disinfection contact time (a contact time of 60 to 100 minutes at a chlorine concentration of 1mg/L), and that consideration be given to use of a baffled contact tank of sufficient capacity to provide the required contact time at the chlorine level appropriate to this method or use of ultraviolet disinfection.

The Order also stated that, in the event that Well 5 was taken out of service for any reason, the municipality would ensure that there was no means by which it or water in it could contaminate the distribution system and that the municipality would ensure that there was a complete physical separation of the well from the distribution system.

The Order also instructed the municipality to implement the proposed groundwater study, hydrogeology investigation and well integrity testing that it proposed in its May 31, 2000 report, and to submit an interim report on the results of the work by July 14, 2000 and a final report by August 15, 2000.

On July 27, 2000, Order F0007727 extended these deadlines for the interim and final reports to August 18, 2000 and September 8, 2000 respectively. On September 8, 2000, the deadline for the final report was further extended to September 18, 2000 by Order F0007730.

Field Order F0007724

On June 13, 2000, Ministry Order F0007724 ordered the Municipality and the PUC to decontaminate the water supply system and all plumbing connected to it. It included an access order that required that each occupant in Walkerton provide access to those carrying out the work, including access to the inside of any dwelling or other building connected directly or indirectly to the water supply system.

Field Order F0007725

Ministry Order F0007725, issued on June 13, 2000, reaffirmed the order to the Municipality to implement the proposed groundwater study, hydrogeological testing, and well integrity testing described in its May 25, 2000 report in complying with Order F0007721.

This Order also set out requirements for residents to provide access to persons engaged by the municipality to carry out the work described above.

Field Orders F0007726 and F0008973

On July 24, 2000, a Ministry Order ordered the municipality to implement the OCWA proposal to replace all 100 millimetre watermains in Walkerton by September 8, 2000. On September 8, 2000, this deadline was extended to September 28, 2000 by Order F0008973.

Field Order F0007728

On August 9, 2000, the Ministry issued an Order to the PUC requiring it to submit a report to the Ministry no later than August 25, 2000 containing:

- all analytical results from chemistry and bacterial sampling taken at pumphouses, distribution systems and observation wells or any other location of the Walkerton water system from January 1999 to May 2000.
- the sampling methodology and analytical procedures used in relation to the sampling and analysis referred to in the above; and
- all records of water taking and chlorination for each well for the period January 1999 to August 9, 2000, including chlorine residual measurement records in the distribution system with location, date and time of day included.

The Order also required that the Walkerton PUC provide a report to the Ministry and OCWA (which was now operating the system, consistent with the Order of May 25, 2000) on whether or not chlorination system changes at Wells 6 and 7 were providing more representative residual chlorine values.

The Order also stipulated that the report's findings be verified through an assessment of historical chlorine meter readings and back calculations from the flow rates and pounds of chlorine used. The Order required that this report include an assessment of historical operations dating from at least January 1, 2000.

The PUC appealed section 2.2 of this Order to the Environmental Appeal Board. At the time of publication, the appeal has not been heard.

Field Order 0007729

Order F0007729, issued on August 24, 2000, ordered the municipality to ensure that the ongoing disinfection of its water supply conformed with disinfection procedure requirements set out in the ODWS.

It also required the municipality to reduce chlorine input values by approximately 0.5 mg/L per week, provided that disinfection conformed with ODWS disinfection procedures.

The Order stipulated that the bacteriological monitoring and reporting required by Order F0007721, be continued and reporting of it be provided as part of the municipality's weekly update reports.